CHAPTER 3: CHEMISTRY OF SOME *SPHAGNUM*-DOMINATED PEATLANDS IN WESTERN WASHINGTON

This chapter looks at the chemical character of water from peatlands dominated by *Sphagnum* moss. After establishing some basic parameters of the chemical environment, precipitation data from western Washington is presented, followed by data from four *Sphagnum*-dominated peatlands. Water chemistry data is taken from environmental reports submitted as part of development review requirements in King County. Data from both the *Sphagnum* mat and the peripheral moat area (lagg in Scandinavian terminology) are provided when available. Regional groundwater and surface runoff data are also presented and compared to data for the *Sphagnum*-dominated peatlands. Chemical characteristics of other freshwaters in western Washington are presented for comparison and contrast. In addition to data characterizing *Sphagnum*-dominated peatlands and other waters in western Washington, chemical data are presented for drainage from a disturbed peatland.

3.1 Basic Chemistry Considerations in Acidic Peatlands

Peatlands have historically been classified along a gradient from the most acidic, base-poor systems (bogs), to those with circumneutral waters, to alkaline, base-rich systems (rich fens). This bog-fen continuum is discussed in Chapter 1. *Sphagnum*-dominated peatlands are on the acidic, base-poor side of the continuum. The trait of acidity is one of the most important characteristics distinguishing *Sphagnum*-dominated peatlands from other peat-accumulating wetlands. Many investigators have defined peatland classes using pH ranges as one of the variables separating peatland types. From early schemes to more recent ones (Sjors 1950; Malmer 1986; Vitt, et al. 1989) there has been much overlap between these ranges, although all investigators consider bogs to be the most acidic peatland type. Depending on the investigator and location, other *Sphagnum*-dominated peatlands (sometimes termed poor fens) can have pH values that are close to, and overlapping, the acidity threshold set for bogs. Table 3.1 indicates some of the pH values set by various investigators for bogs and poor fens. Note that terminology is used differently by different investigators, and not all poor fens are necessarily *Sphagnum*-dominated.

In addition to differences in pH, *Sphagnum*-dominated peatlands are also exceptional in that the carbonate-bicarbonate buffering system typical of most surface waters is almost entirely absent.[1] The carbonate-bicarbonate buffering system is based on the dissolution of atmospheric carbon dioxide gas in water. At low pH, carbon dioxide forms carbonic acid. As pH increases beyond 6, carbonic acid dissociates into positively charged hydrogen ions (H^+) and negatively charged bicarbonate ions (HCO_3^-). At higher pH (over 10), carbonate (CO_3^{-2}) is favored in the equilibrium. Figure 3.1 shows a carbonate-bicarbonate equilibrium diagram (Hutchinson 1957). Since the waters of

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[1] A buffering system plays a key role in the ability of water to resist changes in pH as strong acids or bases are introduced. The ability to resist changes in pH can be important for some aquatic organisms. Some species of fish, freshwater sculpin, for instance, are highly sensitive to changes in pH, and cannot live in systems where the pH fluctuates too broadly.

TABLE 3.1 pH distinctions between bogs and poor fens, various researchers.

Investigator	Country	*Sphagnum*-dominated peatland		
		Bog		Poor Fen
Sjors (1950)	Sweden	3.7 - 4.6	3.8 - 5.2 (extreme poor fen)	4.5 - 6.5
Gorham (1950)	England	3.7		---
Malmer (1986) Fig 5	Sweden	3.4 - 4.2		4.0 - 5.8
Glaser (in Wright et al. Ed: 1992)	Minnesota	< 4.2		4.2 - ---
Larsen (1982)	N. Michigan	4.1 (avg. of 6)		---
Zoltai & Johnson (1987)	Canada	4.5		4.8
Vitt & Bayley (1984)	Ontario, CA	4.0 - 5.6 (*Sphagnum*-dominated)		
Vitt & Chee (1990) Table 1	Alberta, CA	---		4.5 , 4.8 (Spring / fall averages)
Nicholson & Vitt (1994) Table 1	Elk Is. Natl.Park, Alberta, CA	3.5 - 3.6		4.0 - 4.5
Vitt et al. (1995) Table 2	Alberta, CA	3.9		5.4
Vitt et al., 1990 Table 2	coastal B.C., CA	4.1 - 4.8		4.4 - 6.6
Malmer et al. (1992) Table 3	Prince Ruppert, B.C., CA	3.7 - 4.9		4.4 - 6.7
Thorman (2000)	Alberta, CA	3.9		5
Summary	Range	3.4 - 4.9		4.0 - 6.7

Shaded cells are studies of maritime West Coast peatlands.

Sphagnum-dominated peatlands typically have pH values well below 5, it is too acidic to allow the dissociation of carbonic acid, thus the buffering effect of bicarbonate and carbonate ions typical of most waters, is not operative.

Instead of the typical carbonate-bicarbonate buffering system, the waters of *Sphagnum*-dominated peatlands are rich in organic acids. Gorham et al. (1984) states that both humic substances and aluminum contribute to buffering at pH values less than 5, but goes on to note that their capacity to resist acidification processes has not been measured. Some local investigators also refer to these organic acids as a buffering system (Herrera 1993). However, it is not clear to what extent, if any, organic acids react with bases to buffer changes in pH in the same manner as carbonate and bicarbonate ions. Work by Munson and Gherini (1993) suggests a more complex interaction between mineral and organic acids on the actual buffering capacity of waters.

An interesting application of this basic chemical equilibrium comes into play in looking at the distribution in acidity of peatlands worldwide. In 1984, Gorham et al. noticed a bimodal distribution in the acidity of Minnesota peatlands. These investigators found that peatlands tended to be either acidic, with pH less than 5, or basic, with pH greater than 6. Fewer peatlands were in the intermediate range between pH 5 and 6. Data were also presented for Swedish peatlands, which showed a similar distribution. This relative scarcity of peatlands in the range of pH 5 to 6 is near the point in the carbonate-bicarbonate

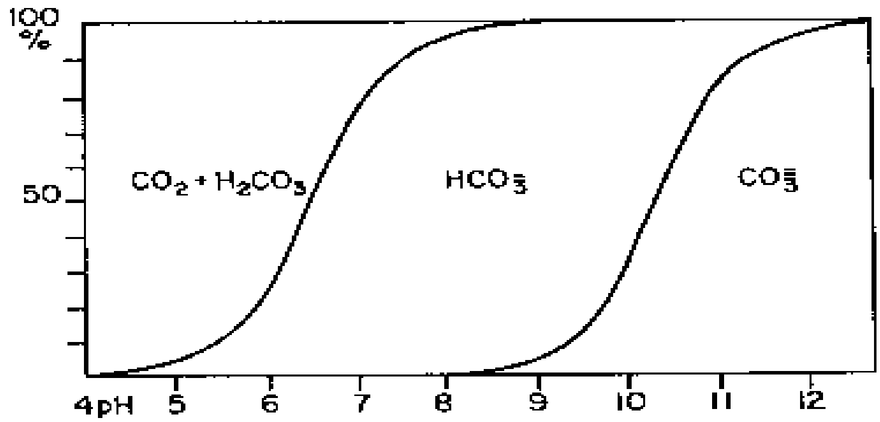


FIGURE 3.1 Carbonate-bicarbonate equilibrium diagram

equilibrium that bicarbonate alkalinity drops rapidly to zero. At this point, acidification by *Sphagnum* can become the dominant influence in acidification, which is hypothesized to progress rapidly, perhaps on the order of one to two hundred years. Vitt and Kuhry (1992) have suggested that this bimodal distribution of pH may be due to the short length of time it takes to complete the switch to *Sphagnum* domination in a peatland once the pH decreases to about 6.

Since rainwater is a predominant source of water, it plays an important role in the dynamics of *Sphagnum*-dominated peatlands. Therefore, the chemical properties of rainwater are of interest as a reference point in understanding the chemistry of acid peatlands and will be discussed in Section 3.2. However, some general observations are of interest here. The water of some *Sphagnum*-dominated peatlands has long been recognized as being more acidic than rainwater (Moore and Bellamy 1974; Crum 1992). The sources of this enhanced acidity have been explored by a number of investigators (Clymo 1963 and 1964; Gorham 1956; Hemond 1980; Oliver et al. 1983; Munson and Gherini 1993).

Three basic mechanisms of acidification are recognized: **cation exchange, dissociation of organic acids** and **sulfate reduction**. Of these, **cation exchange** is perhaps the easiest to understand but considered by Hemond (1980) to be a relatively minor source of acidity. In investigating ion exchange as a method of acidification, Clymo (1963) identified the unesterified polyuronic (galacturonic) acids on and within the cells of *Sphagnum* mosses as the active exchange site. He also found that the cation exchange ability is related to height above the free water table. Clymo, working in English bogs, estimated that a pH of 4.5 could be maintained by cation exchange in the new *Sphagnum* growth using only the cations supplied by rainwater. However, he also found that only a portion of that exchange ability actually occurs.

In cation exchange, the polyuronic acid on the inside and outside surfaces of the cell walls of living *Sphagnum* binds with free cations in the water (Vitt, personal communication 2000). In doing so, the acid gives up hydrogen ions, the number depending on the charge of the cation captured. This process is an obligate one – it occurs in living *Sphagnum* whenever cations are in close enough proximity to the cell wall. Figure 3.2 show a schematic of the cation exchange process.

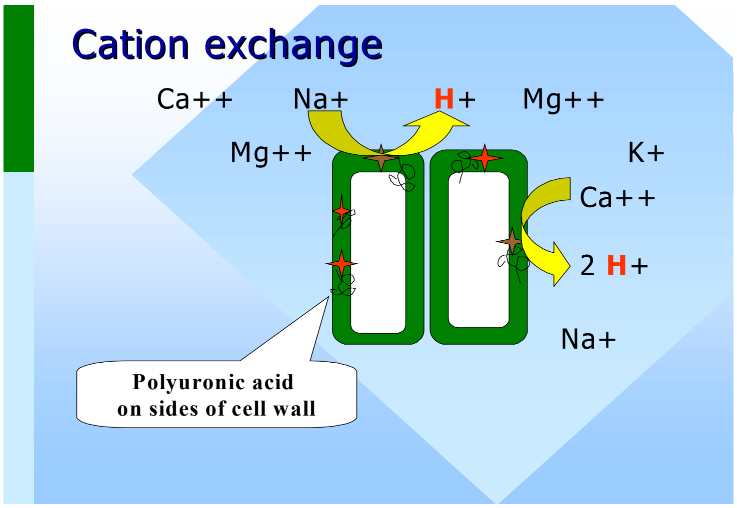


FIGURE 3.2 Cation exchange: a schematic representation.

Organic acids were the focus of a study by Hemond (1980). In investigating Thoreau's Bog (Massachusettes), Hemond concluded that "…the dissociation of these weak [organic] acids is adequate to account for the observed pH of the bog," which was as low as 3.8. Oliver at al. (1983) found that humic acids, a type of organic acid, made a significant contribution to the ionic balance of highly colored waters, and that mineral ions (e.g. Ca^{++}, Mg^{++}, $SO^{=}_4$, etc) were insufficient to account for observed acidity in humic waters in Nova Scotia. Thurman (1985) emphasized this same conclusion. These observations support the conclusion that cation exchange is only one of several possible factors causing the acidity in peatland waters.

Sulfate reduction, a third mechanism of acidification in peatlands, was investigated by Gorham (1956), who considered the oxidation of hydrogen sulfide released from the anaerobic peat to be the source of high sulfate concentrations in English bog pools. He assumed sulfate, in its equilibrium condition within the bog, was present as sulfuric acid, and the source of acidity. This idea was developed further by Gorham in 1967 (as reported by Hemond 1980). Acid rain was identified by Gorham (1956) and also mentioned by Clymo (1963) as being an additional potential source of peatland acidity.

Munson and Gherrini (1993) developed a predictive model to determine changes in the H^+ content of Adirondack lake waters due to changes in both mineral acidity and dissolved organic carbon (DOC) (organic acids are an important source of DOC). Sulfate reduction would be included in mineral acidity in this model. Using empirical data from Adirondack lakes, they found that both mineral and organic acidity interacted in predictable ways to affect pH. Specific studies concerning the importance of the three processes described above have not been done for western Washington *Sphagnum*-dominated peatlands.

Another important characteristic of *Sphagnum*-dominated peatlands is the presence of a vertical gradient of dissolved oxygen (D.O.) in the *Sphagnum* mat. It is particularly pronounced in *Sphagnum*-dominated peatlands characterized by hummocks and hollows. There are three distinct zones identifiable in profile through a *Sphagnum* hummock. The uppermost zone is characterized by living *Sphagnum,* and the spaces between the *Sphagnum* stems are not permanently saturated. Zone two lies immediately below the upper zone. It consists of living and partially decomposed *Sphagnum*. The interstitial spaces are typically filled with water and have a measurable dissolved oxygen content. Zones one and two combined are called the acrotelm. Zone 3 lies below the acrotelm and begins where dissolved oxygen is depleted. In this zone, peat decomposition by aerobic processes ceases, and only slow anaerobic decomposition takes place. Zone three is called the catotelm. Malmer (1986) has reported that in Swedish bogs, both the amplitude of water level fluctuations, as well as the duration of low water level in summer, affect the depth of the acrotelm. Figure 3.3 represents these chemically and ecologically distinct zones.

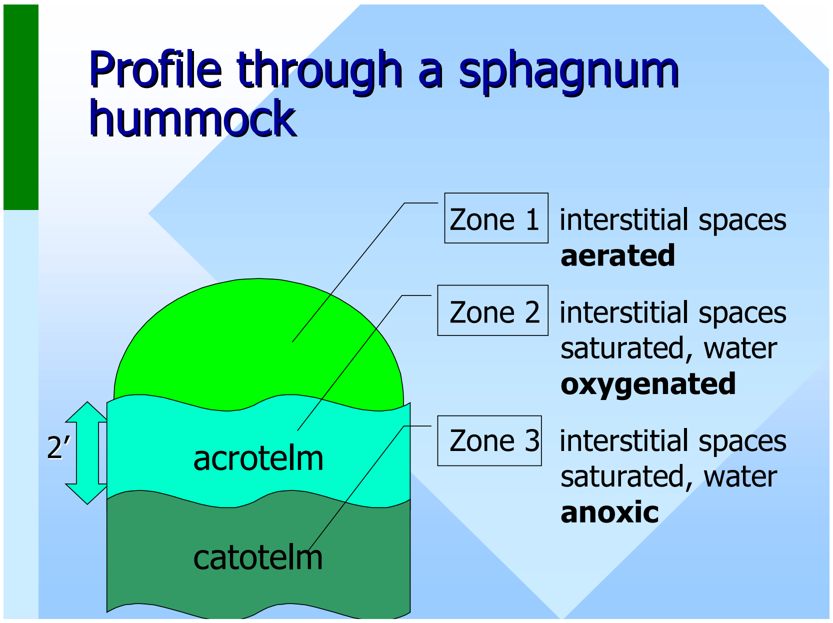


FIGURE 3.3 Vertical zones through a *Sphagnum* hummock.
Note: the 2-foot depth of the acrotelm indicated in the Figure is based on measurements, Little Lake, Snohomish County, Washington.

3.2 Rainwater Chemistry in Western Washington

Since rainwater is a major influence upon *Sphagnum*-dominated peatlands, the chemical characteristics of rainwater are an interesting reference point. Rainwater is different chemically from ground and surface waters, which are enriched by contact with mineral soils, bedrock and biological processes. Rainwater is influenced primarily by atmospheric gases, and in developed areas, anthropogenic contaminants. When dissolved in water, carbon dioxide, a common atmospheric gas, dissociates to form carbonic acid. Therefore, rainfall naturally tends to be on the acidic side. (Nitrogen, although a major atmospheric gas, does not dissociate readily in water, hence nitric acids are not typically present in rainwater from unpolluted areas.) In addition to natural acidity, rainwater is soft, meaning that earth-derived cations such as calcium and magnesium are present only in low concentrations. Since mineral acidity is low in rainwater, purely rainwater-influenced, or ombrogenous, peatlands probably do not depend solely on cation exchange to develop their acidity. Cation exchange would be a more important factor in developing acidity in peatlands that have more contact with surface or groundwater (that is, in the poor fens category in many peatland classification schemes: see Chapter 1 for a discussion of peatland classification).

Data from western Washington, collected as part of the National Atmospheric Deposition Study (NOAA website May 2000) are given in Table 3.2. The data are annual averages from 1995 and 1998 for Olympia and Bellingham, both medium-sized cities. The data show that rainfall is moderately acidic, the average pH being about 5. Cation concentrations are very low and similar for the two cities. Calcium averages between 0.02 and 0.03 mg/L and magnesium about 0.02 mg/L. Sodium, often higher in maritime climates due to the incorporation of salt from the ocean, is similar for the two cities: 0.15 mg/L to 0.16 mg/L. Potassium concentrations range from 0.009 to 0.017 mg/L. Sulfate is relatively high, averaging 0.35 mg/L in Olympia and 0.2 mg/L in Bellingham. Chlorine, which tends to be higher in ocean-influenced climates, averages about 0.32 mg/L in Olympia and 0.22 mg/L in Bellingham.

Macronutrient data (phosphorus and nitrogen) are not given in the NOAA database. Precipitation reaching western Washington from the Pacific might be thought to have little opportunity to pick up nutrients, there being few sources that might cause enrichment. Local data indicate that human activity, especially motor vehicle traffic, may be influencing the composition of urban rainwater in the Puget Sound area. Rainfall data were collected at two locations in the Seattle area by the Puget Sound Wetlands and Stormwater Management Research Program (PSWSMRP) from mid-1988 to 1990. One location, near the Factoria interchange in Bellevue, represents a very urban situation. At the Factoria interchange, two major freeways cross – Interstate 5 and Interstate 405. The second location, Patterson Creek wetland 12 (PC 12), is at the eastern edge of the Lake Sammamish plateau near the headwaters of the Patterson Creek. At the time of rainfall sampling, the Patterson Creek location was rural in character.

Rainfall for the study was collected in 30-gallon plastic garbage cans lined with plastic garbage can liners. The cans were placed in the middle of an open area near each of the wetlands studied. Care was taken to place the cans so that precipitation would fall directly into the can without contacting overhead vegetation (Lorin Reinelt, personal communication May 10, 2000). The rainwater collected was transferred to laboratory-supplied sample bottles and analyzed at a certified environmental laboratory operated by Metro (now the King County Environmental Laboratory). Parameters analyzed were chosen for a nutrient mass balance study of the two wetlands: hence minor nutrients and cations data were not collected. Summary statistics are also presented in Table 3.2.

TABLE 3.2 Precipitation chemistry, western Washington area.

National Atmospheric Deposition Program

Annual average concentrations 1994-1998

	pH	conductivity	Ca	Mg	Na	K	SO4	Cl	TP	SRP	NO3	NH3	TKN
		umho/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Olympia, WA													
1995	5.0		0.02	0.019	0.180	0.022	0.3	0.29					
1996	4.9		0.02	0.013	0.132	0.013	0.4	0.38					
1997	4.9		0.02	0.025	0.220	0.017	0.4	0.38					
1998	4.9		0.03	0.017	0.124	0.015	0.3	0.22					
Average	4.9		0.02	0.02	0.16	0.02	0.4	0.32					
Bellingham, WA													
1994			0.07	0.025	0.172	0.017	0.3	0.29					
1995	5.0		0.01	0.012	0.115	0.005	0.2	0.19					
1996	5.0		0.02	0.022	0.215	0.007	0.2	0.21					
1997	5.0		0.02	0.018	0.156	0.009	0.2	0.27					
1998	5.0		0.02	0.011	0.084	0.005	0.2	0.15					
Average	5.0		0.03	0.02	0.15	0.01	0.2	0.22					
Factoria interchange, Bellevue, WA June, 1998 - May 1990													
Average	4.7	28.2 *							0.069	0.016	0.245	0.129	0.579
n	11	12							12	11	11	11	12
variance(s2)	0.4	499							0.016	0.001	0.061	0.014	0.269
s	0.7	22							0.128	0.028	0.247	0.119	0.518
Patterson Creek wetland 12, Nov 1988 - April 1990													
Average	4.7	12.3 *							0.030	0.016	0.280	0.145	0.648
n	8	8							9	8	8	8	9
variance(s2)	0.18	84.8							0.001	0.0007	0.12	0.013	0.35
s	0.42	9.2							0.034	0.026	0.348	0.116	0.589
Pine Lake, East Lake Sammamish Plateau, Dec 1979 - Apr 1980													
Average										0.003	0.160		1.062
n										6	6		6

* If corrected for hydrogen ion concentration per Sjors (1950), the values are 21.7 and 5.8 uS/cm for the Factoria and PC12 stations, respectively.

The pH and nitrogen data (all forms, NO_3, NO_2+NO_3 and TKN) is fairly similar for both stations, although the variance is high. The pH averages 4.7, and ranges as low as 3.8 to as high as 6.4. Both extremes are at the Factoria station. Nitrate (NO_3) averages 0.245 mg/L at Factoria and 0.280 mg/L at PC12, relatively high values when compared to lake water. Ammonia (NH_3) is about half the nitrate concentration: 0.129 mg/L at Factoria and 0.145 mg/L at PC 12. Total Kjedahl nitrogen (TKN) is higher than either nitrate or ammonia, and somewhat higher at PC 12 (0.648 mg/L) than at Factoria (0.579 mg/L).

The Factoria station shows high values for conductivity and phosphorus. Conductivity is a measure of the ability of water to conduct an electric current (Standard Methods for the Examination of Water and Wastewater 1992). The values average 28.2 μS/cm for Factoria and only 12.3 μS/cm for the PC 12 station. If corrected for hydrogen ion content per Sjors (1950), the respective conductivity values are 21.7 and 5.8 μS/cm respectively for the two stations. Total phosphorus concentration averages 0.069 mg/L at Factoria and 0.03 mg/L at PC 12. Both these values are unexpectedly high for rainfall and substantially higher than typical lake water in the region. Soluble reactive phosphorus (SRP) is also relatively high at both stations: 0.016 mg/L at both Factoria and PC 12. None of the differences in averages between the two stations are statistically significant because of the high degree of variability in the data. One of the most likely sources of variability is emissions from vehicles and the combustion of fossil fuels. The detergent additives in gasoline, as well as increased dust and particulates, are likely sources of increased phosphorus.

An older local precipitation data set was collected for the Pine Lake Restoration study in December 1979 through April 1980 (Dion et al. 1983). The study sought to quantify the nutrient inputs into a nearby lake. TP was not determined, but SRP averages 0.003 mg/L for the 6 samples collected. Nitrate averages 0.160 mg/L. The SRP value in this earlier study was almost an order of magnitude lower than that found at Factoria and Patterson Creek ten years later. Nitrate is also lower in the earlier Pine Lake study than in the Factoria and Patterson Creek stations, but not as dramatically so. These data, also shown in Table 3.2, appear to support the conclusion that urbanization can increase the nutrient concentration of precipitation.

3.3 Chemistry Data for *Sphagnum*-dominated peatlands

Sphagnum **mat and moat water chemistry: overview**

A limited amount of water chemistry data was located for four *Sphagnum*-dominated peatlands in western Washington: ELS21, ELS 34, LCR 16 and PC 17. Table 3.3 summarizes the physical characteristics of these systems. Figure 3.4 gives general locations of these peatlands, along with two other locations discussed later in this Chapter. Additional field data of dissolved oxygen profiles are also presented.

General chemistry is summarized in Table 3.4. Two of these four peatlands, ELS 21 and ELS 34, are considered typical of Puget Sound area systems. LCR 16 has a wider moat than is typical, and PC 17 is dryer than most *Sphagnum*-dominated peatlands and has a poorly developed, shallow moat. Data were collected by environmental consultants and analyzed at certified laboratories. Complete data are presented in Appendix C for Chapter 3.

TABLE 3.3 Physical Characteristics of *Sphagnum*-dominate Peatland Chemistry Localities

	ELS 21	ELS 34 (Queen's bog)	LCR 16	PC 17
Area of peatland hectares (acres)	5.4 (13.4)	7 (17.5)		1.2 (2.87) (DEA,1998)
Area of watershed hectares (acres)	103 (257)	68 (171)	98 (245)	
Soil type (from 1973 Soil Survey)	Orcas peat	No designation	Seattle muck	Seattle muck
Landscape position	Headwater	Headwater	Plateau	Headwater
% Disturbance in watershed	Largely undeveloped at time of data collection. Past logging of watershed.	About 60% developed. Road along part of undeveloped basin boundary	Close to 70% developed	Road along 50% of basin boundary
Inflow / outflow streams	Two intermittent inflow streams, one intermittent outflow stream.	No inflow stream. One outflow stream, Laughing Jacobs Creek.	Two intermittent inflow streams. Headwaters of Madsen Creek.	No inflow, no outflow.
Moat characteristics	Broad, shallow spirea moat.	Narrow moat except at pipeline cut through mat.	Very wide moat, over 4' deep.	Narrow, shallow moat.
Tree growth on mat	No trees on mat.	Stunted hemlock common.	Few stunted trees on mat.	Few trees on mat.
Dominant shrub vegetation	*Ledum groenlandicum*	*Ledum groenlandicum, Kalmia microphylla*	*Ledum groenlandicum, Kalmia microphylla, Vaccinium oxycoccos*	*Ledum groenlandicum, Kalmia microphylla*
Depth of peat meters (ft)	6 (20)	No data	No data	5 (17) deepest
Wetness or dryness of system	Fairly dry mat	Wet	Wet	Very dry mat, little water between hummocks.
Condition/characteristics of vegetation	Wide spirea moat, mat vegetation disturbed by off-road vehicle in a portion of the bog.	Invasives, especially *Typha latifolia*, at gasline cut and at north lagg. Hummocks taller with fewer invasives in eastern (upstream) portion of mat.	Invasives encroaching at edges of mat and willow established at outlet end of peat area.	Dry peat. Shrubs relatively tall, few invasives.

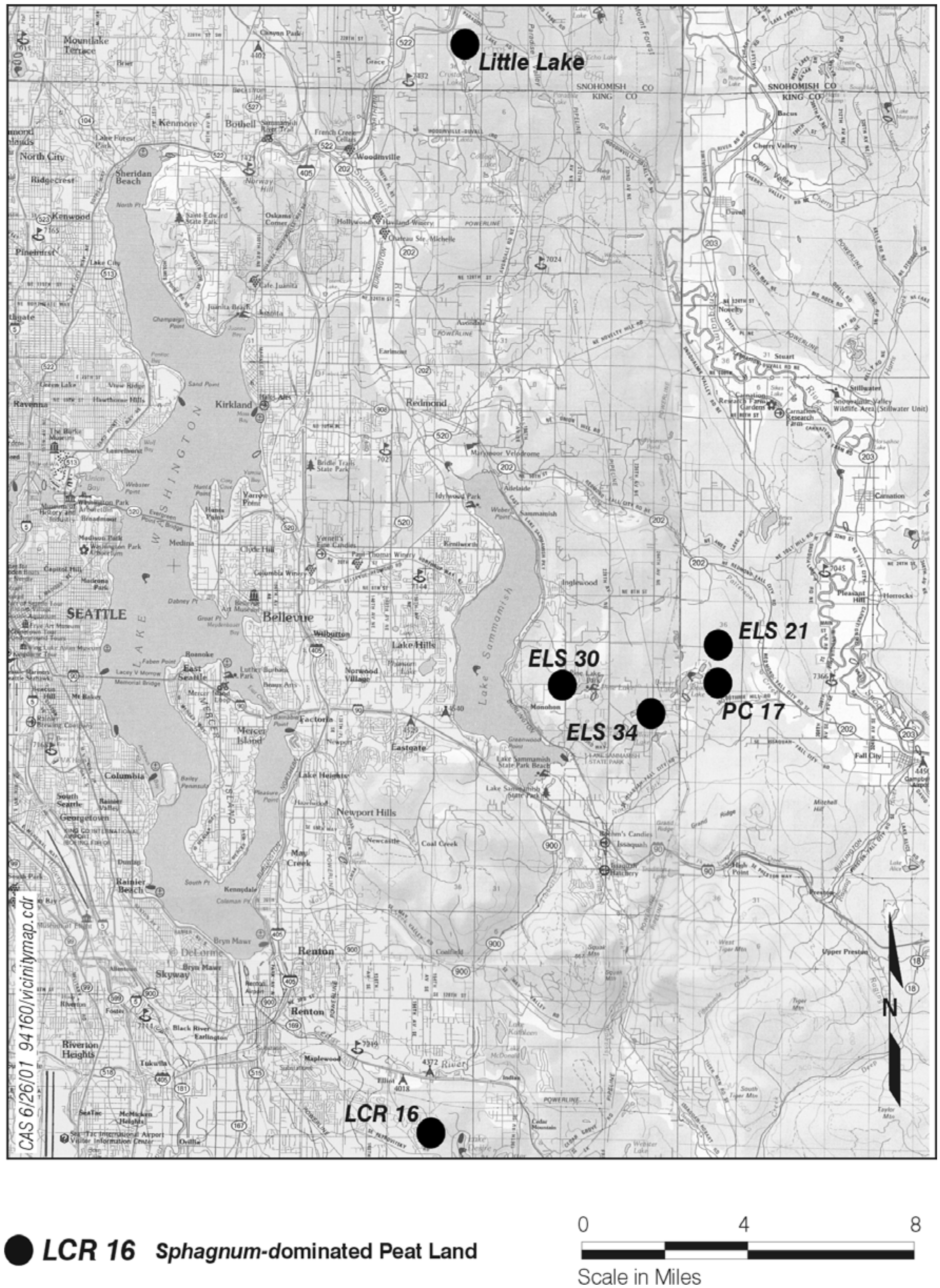


Figure 3.4 Vicinity map for *Sphagnum*-dominated peatlands discussed in this Chapter.

TABLE 3.4 Summary of water chemistry data of four *Sphagnum*-dominated peatlands, King County, Washington.

Parameter		ELS21				ELS34		LCR16				PC17 *			
		Mat	N	Moat	N	Mat	N	Mat	N	Moat	N	Mat	N	Moat	N
pH		4.2	7	5.9	19	4.6	17	4.17	3	6.9	9	4.66	1	5.05	1
alkalinity	mg $CaCO_3$/L	<1	2	<3.7	8			< 1	3	16.4	9	3.8	1	4.90	1
acidity	mg $CaCO_3$/L	15.7	3	<1.3	6							473	1	333	1
hardness	mg/L	4	3	8	14							5.87	1	12.3	1
conductivity	uS/cm	41.8	7	32.2	18	50.2	14	32.6	3	60.3	9	80.0	1	390	1
corrected cond	uS/cm	22	7	31	18	40.0	14	9.3	3	NA		72	1	387	1
Ca	mg/L	0.72	1	1.90	6			0.38	3	4.9	9	4.73	1	9.98	1
Mg	mg/L	0.28	1	0.77	6			0.16	3	2.1	9	1.14	1	2.33	1
Na	mg/L	0.59	1	1.78	6			0.78	3	2.5	9	2.28	1	4.95	1
K	mg/L	0.5	1	0.60	6			1.28	3	0.6	9	2.03	1	2.97	1
sulfate	mg/L							< 1.18	3	5.8	9				
Cl	mg/L							1.77	3	2.7	9				
DO	mg/L	1.9	7	3.8	10			1.4	2			4.3	1	6.5	1
turbidity	NTU	17	6	5.0	19							6	1	94	1
TP	mg/L	0.072	3	0.051	14	0.60	17	0.23	3	<0.025	9	0.72	1	1.37	1
SRP	mg/L	< 0.005	3	<0.008	14	0.39	17					0.56	1	0.43	1
NO3	mg/L	< 0.34	3	<0.102	13							0.03	1	0.07	1
NO2+NO3	mg/L					0.4	11	0.05	3	<0.161	9				
NH3	mg/L	< 0.05	3	<0.033	14	1.72	14	0.08	3	0.06	9	2.01	1	3.1	1
TKN	mg/L							3.55	3	0.4	9				

* Note: the PC 17 sample was taken during summer drought conditions
Also note high turbidity in PC17 moat sample

General considerations for water chemistry sampling

There are no standardized protocols for sampling peatland waters. This means that water from very different situations could be sampled and represented as characteristic of the peatland. The following are types of peatland water that could be sampled:

a) water from natural inter-hummock pools that have living *Sphagnum* as a substrate

b) water from natural depression pools in the mat that have muck (or dead peat but no living *Sphagnum*) as substrate

c) water from a deep central pool that is bordered by living *Sphagnum*

d) water from an artificial depression made in the living *Sphagnum* mat

e) water from a piezometer installed at a depth of 0.3-0.6 m (1-2 ft) in the mat. By convention for groundwater sampling, piezometers are typically bailed, that is, the water initially withdrawn is discarded and the piezometer allowed to refill. The refill water is typically used for the chemistry sample.

f) pore water squeezed from the living sphagnum.

Each of these sample locations/types has different characteristics and are likely to yield different chemical characteristics. One difference is the gradation in redox potential with depth, from the presence of oxygen in surface water, to the lack of oxygen in the acrotelm. In addition, decay of *Sphagnum* also increases with depth, resulting in the release of nutrients. Vitt et al. (1995) show vertical concentration data for several chemical parameters for a *Sphagnum*-dominated peatland in Alberta, Canada. Seasonal variation in nutrients would also differ, especially between surface and deeper locations, depending on the location of the sample. Many studies have been explicit about the type of water collected, but others have not. Therefore, it is difficult to compare results from study to study. For the S*phagnum*-dominated peatlands discussed below, samples were collected differently. Two of the peatlands were sampled using piezometers (ELS 34 and LCR 16) and two from natural surface depressions (ELS 21 and PC 17).

Another consideration in water chemistry sampling is whether the samples are filtered or not, and the size of filter pores used in filtering. A number of the parameters involve digestion of the sample by strong reagents. If fragments of organic material are contained in the sample, this material would contribute to the concentration being determined unless the sample was filtered. The samples from LCR 16 were filtered before nutrient determinations were made. It is not known whether other samples were filtered.

East Lake Sammamish (ELS) 21

ELS 21 is located just northwest of Beaver Lake in King County, Washington (see Figure 3.4). It appears to be formed in a kettlehole, 6.1 m (20 feet) deep. Kettlehole peatlands have relatively steep sides and are formed by stranded blocks of glacial ice which subsequently melt. Two intermittent streams contribute flow to this peatland in winter. An outlet stream, also intermittent, currently drains to Beaver Lake. This stream may have been created when the road around the lake was built in the 1950s. Before the road was built, there may not have been a defined outlet channel. The topographic gradient between ELS 21 and Beaver Lake is very slight.

Data were collected in 1993 and in 1996 in connection with a development proposal in a portion of the watershed (David Evans & Associates, Inc. 1993 and 1997). Three of the four sampling dates were in late spring: one was in December. Season variation may be represented in the data set. Mat samples were taken from natural depressions. Moat samples were taken near the surface.

Data from the *Sphagnum* mat show low pH, D.O. and cation concentrations. Average pH is 4.2, and ranges from 4.12 to 4.5. D.O. averages 1.9 mg/L (standard deviation, s, = 1 mg/L). Calcium is 0.72 mg/L, magnesium 0.28 mg/L, sodium 0.59 mg/L and potassium 0.5 mg/L. Anion data were not collected. Hardness averages 3.7 mg/L (s = 0.4 mg/L). Since hardness is defined as the sum of the calcium and magnesium ions, this value is high. It is not known why agreement between the hardness value and the component cations is poor.

Data from the moat area were taken from various locations ranging from those near the intermittent inlet streams to stations adjacent to the *Sphagnum* mat. Average moat pH is 5.9 (s = 0.9), varying from 4.6 to

8.1, reflecting a wide range in acidity in the sample locations. Dissolved oxygen is somewhat higher than for the mat samples, averaging 3.8 mg/L, but the standard deviation is high (s = 3 mg/L). Cations were sampled at six stations, all on one date. Calcium averages 1.9 mg/L, magnesium 0.77 mg/L, sodium 1.8 mg/L and potassium 0.6 mg/L. Hardness is 8 mg/L, higher than the mat average of 4 mg/L and still high compared to the sum of the measured moat calcium and magnesium concentrations. Calcium to magnesium ratios are often used to indicate dominant cations. In ELS 21, the Ca/Mg ratio for the *Sphagnum* mat samples is 2.6:1, relatively typical of *Sphagnum*-dominated peatlands.

Conductivity was corrected for hydrogen ion activity following Sjors (1952). Mat reduced conductivity averages 22 μS/cm, while moat conductivity averages 31 μS/cm. This difference is less pronounced than expected, perhaps reflecting several fairly acidic stations in the moat samples.

Nutrients show slightly higher values of both phosphorus and nitrogen species in the *Sphagnum* mat pool water than in the moat. Total phosphorus concentrations are similar, averaging 0.07 mg/L in the mat and 0.05 mg/L in the moat. Soluble reactive phosphorus is near the detection level in both mat and moat locations. Nitrate + nitrite is higher than ammonia values at both locations, reflecting oxidizing conditions at the surface. In the mat, nitrate + nitrite averages less than 0.34 mg/L while the moat concentration averages less than 0.10 mg/L. Ammonia concentrations are similar in the mat and moat stations, averaging less than 0.05 mg/L in the mat and less than 0.03 mg/L in the moat.

East Lake Sammamish (ELS) 34, Queen's bog

ELS 34 is located near a tributary to the headwaters of Laughing Jacobs Creek in a depression between two parallel ridges running east-west. The peatland is teardrop-shaped, with the narrow end at the outlet on the western side of the wetland. At approximately the center of the peatland, the *Sphagnum* mat was cut during the installation of a natural gas pipeline in the early 1960s. The open water of the cut never revegetated. Over time the areas of the mat adjacent to the open water area eroded, and the open water area increased. Non acid-adapted vegetation such as *Typha latifolia* and *Juncus effusus* became established along the mat at the cut margins. The mat area nearest the outlet has been colonized by *Spirea douglasii*, as is the north portion of the upper mat receiving drainage from a county road. Figure 3.5 shows a view of the *Sphagnum* mat from the adjacent north ridge. Approximately 60% of the south watershed is developed in residential land uses. Southeast 32nd St. follows along the ridgeline at the northern edge of the drainage basin (see Figure 3.6).

Figure 3.5 Queen's Bog (ELS34) looking across the *Sphagnum* mat

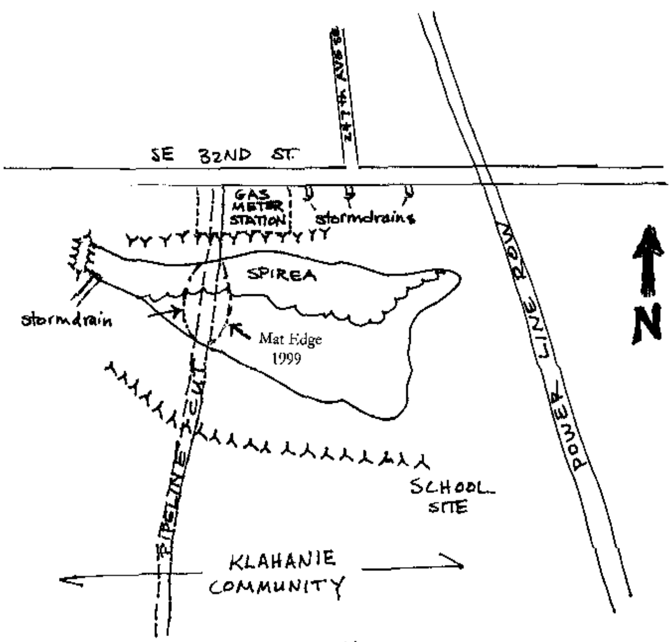


Figure 3.6 Sketch of Queen's Bog vicinity

The data from Queen's bog were gathered during the Puget Sound Wetlands and Stormwater Management Research Program (PSWSMRP) and are presented separately in topics below. Only a limited number of parameters are available for this site; pH, conductivity, nitrate plus nitrite, ammonia, total phosphorus, and soluble reactive phosphorus. Samples for nutrients were taken only in the *Sphagnum* mat. Moat samples were not taken. Although fewer parameters were collected, some parameters were collected over a year-long period, allowing seasonal patterns to be identified. Three stations were sampled from shallow piezometers at the center of the *Sphagnum* mat. The piezometers were bailed prior to sample collection and allowed to partially refill (Personal communication, R. Horner, May, 2000). Table 3.5 summarizes the data, showing each of the six sampling dates. Averages are also included in the Table. The pH data for these stations range from 4.3 to 4.9 and average 4.6. A wider range of stations were also sampled for pH and will be discussed in Section 3.3.2 below.

TABLE 3.5 ELS34 Queen's Bog water chemistry data

Average, 3 stations							
	pH	TP	SRP	NO_3 + NO_2	NH_3	Conductivity	Corrected Conductivity
Date		mg/L	mg/L	mg/L	mg/L	µS/cm	µS/cm
09/13/90	4.3	0.70	0.48	0.03	2.96	50	34
11/19/90	4.9	0.41	0.24	1.2	1.40	62	58
12/13/90	4.4	0.47	0.26	0.073	1.21	47	32
01/17/91	4.6	0.69	0.46	<0.01	1.42	46	37
2/27/91	4.7	0.50	0.39	0.3	1.50	45	38
04/16/91	4.9	0.81	0.52				
Average, all stations	4.6	0.60	0.39	0.40	1.72	50	40
N	17	17	17	11	14	14	14

Total phosphorus and soluble reactive phosphorus concentrations are relatively high compared with typical wetland and surface water values. TP averages 0.60 mg/L, and SRP is 0.39 mg/L. No annual trend was discernable. Nitrogen is most prevalent in the form of ammonia (NH_3), having a higher concentration than nitrate + nitrite (NO_2+NO_3) on all but one sampling date. The mean NH_3 concentration is 1.72 mg/L, whereas NO_2+NO_3 averages 0.40 mg/L, both high values relative to typical surface water concentrations. In January, NO_2+ NO_3 values fell below the detection limit of 0.01 mg/L. Freezing weather had occurred the week before (Personal communication, R. Horner, 2000). NO_2+ NO_3 ranges from 0.01 mg/L to a high of 1.35 mg/L. NH_3 ranges from 0.84 mg/L to a high of 3.41 mg/L.

Corrected conductivity averages about 40 µS/cm. The range is from 18 to 73 µS/cm. Individual sample values are presented in Appendix C, Water Quality Data.

Lower Cedar River (LCR) 16

LCR 16 is located on the Maple Valley plateau above the Cedar River, southeast of the city of Renton, Washington. It is a headwater *Sphagnum*-dominated peatland and is the source of Madsen Creek, a tributary to the Cedar River. The peatland has a relatively broad, wide moat. *Typha latifolia* is established in the moat and around the *Sphagnum* mat, and in some areas grows directly through the *Sphagnum*. Figure 3.7 show a view across the moat looking toward the *Sphagnum* mat. Approximately 70% of the watershed has been developed, including single family residences and a park/playfield.

Water levels in the wetland were measured and were noted to fluctuate up to 31cm (1.2 feet) in the moat. This is considered a relatively high level of fluctuation (Horner, 1996) and probably reflects lack of standard flow control stormwater ponds in the developed areas of the watershed.

It was not possible to measure peat depth in the field due to obstructions at depth, presumably submerged wood. Peat was estimated to be over 3 meters (10 ft) deep based on other peat systems in the vicinity. Data were collected in 1995 and in 1998 in connection with a development proposal in the watershed (Shapiro & Associates, 1998. McGarvey Park Limited Scope Master drainage Plan, Baseline Monitoring Results, revised August, 1998). Earlier sampling dates were of the moat, later dates from the *Sphagnum* mat. Moat samples were taken in December, March and May and may reflect seasonal variation. Mat samples were from a piezometer installed in the *Sphagnum* mat to a depth of 60 cm (2 ft). The piezometer was bailed and allowed to partially fill for each sample date. All mat samples were taken in June, 1998, minimizing seasonal variation.

FIGURE 3.7 LCR 16, view across the moat toward the *Sphagnum* mat

Data from the *Sphagnum* mat show low pH and D.O. values. Average pH is 4.2, and ranges from 4.11 to 4.22. Surface D.O. in the mat averages 1.4 mg/l. Cations concentrations are low. Calcium averages 0.38 mg/L, magnesium 0.16 mg/L, sodium 0.91 mg/L and potassium 1.16 mg/L. The calcium to magnesium ratio is 2.4 to 1, similar to ELS 21.

Data for two anion was collected: sulfate and chloride. Sulfate averages 1.18 mg/L and chloride is 1.77 mg/L on average. Alkalinity is less than 1 mg/L on all sampling dates. Corrected conductivity averages about 9 μS/cm.

Three stations were located in the moat. The width of the moat varied at the three stations from approximately 8 m to over 20 m. The proximity of the sampling sites to the mat also varied. Average pH is 6.9 based on 8 samples (s = 0.2), considerably higher than mat pH. D.O. was not measured in moat stations. Cations were sampled three times – in December, March and May. Values are higher than mat values except for potassium. Calcium averages 4.7 mg/L, magnesium and sodium 2.5 mg/L. Potassium averages 0.6 mg/L, a decrease from the mat concentration of 1.2 mg/L. Conductivity averages 60 μS/cm, an increase over mat conductivity.

Total phosphorus is higher in the *Sphagnum* mat piezometer sample than in the moat. The mat averages 0.23 mg/L TP whereas the moat averages less than 0.025 mg/L TP. Soluble reactive phosphorus was not tested. In the mat, ammonia is slightly higher than the nitrate + nitrite concentration. Nitrate + nitrite averages 0.05 mg/L and ammonia 0.077 mg/L. In the moat, nitrate + nitrite is less than 0.16 mg/L (one data point is below the detection limit of 0.01 mg/L) while ammonia is less dominant at 0.058 mg/L. Total Kjeldahl nitrogen is significantly higher in mat water than in moat water (3.55 mg/L vs. 0.4 mg/L).

Patterson Creek (PC) 17

PC 17 is located near ELS 21 east of Beaver Lake on the Lake Sammamish plateau. PC 17 occupies a surface and groundwater drainage divide between the Patterson Creek basin and the Beaver Lake basin (David Evans & Associates, Inc. 1998). Data were collected only one time, July 1998, in connection with a development proposal in the watershed (David Evans & Associates, Inc. 1998). The consultant report emphasized that because of the dryness of the peatland, there were only limited areas with enough water to obtain a sample, especially on the mat. The sample was taken in a natural depression in the mat after a prolonged period of dry, sunny weather. This single sample may not be representative of *Sphagnum* mat conditions, particularly since evaporation had been occurring and salts would tend to be concentrated in the remaining pools. The same concern applies to the sample from the moat. However, data are presented to allow relative comparisons between mat and moat to be made.

Data from the *Sphagnum* mat show the pH is 4.7 and the D.O. is 4.3 mg/L (standard deviation = 1 mg/L). Cations are also higher than the other peatlands, probably due to evaporative effects. Calcium is 4.73 mg/L, magnesium 1.14 mg/L, sodium 2.28 mg/L and potassium 2.03 mg/L. Alkalinity is 3.8 mg/L, lower than expected from the sum of cation concentrations. Corrected conductivity is 72 μS/cm. Anion data were not collected.

For most parameters, concentrations from the moat area are higher than from the mat. Moat pH is 5.0 and D.O. is 6.5 mg/L. Cations are higher with calcium being 9.98 mg/L, magnesium 2.33 mg/L, sodium 4.95 mg/L and potassium 2.97 mg/L. The ratio of calcium to magnesium is 4.2, indicating relatively higher dominance by calcium than in ELS 21 or LCR 16. Hardness in the moat sample is double that of the mat, from about 6 mg/L in the mat to 12 mg/L. Alkalinity values, both from the mat and the moat, are lower than expected from the sum of cations. Conductivity increases from 72 μS/cm in the mat to 387 μS/cm in the moat sample.

Nutrients, like the cations, are high in both mat and moat samples. Total phosphorus averages 0.72 mg/L in the mat and 1.37 mg/L in the moat. Soluble reactive phosphorus, however, is slightly higher in the mat: 0.56 mg/L versus 0.428 mg/L in the moat. In the mat, nitrate is 0.032 mg/L while the moat concentration is 0.069 mg/L. Ammonia values are very high. Ammonia is 2.01 mg/L in the mat and 3.1 mg/L in the moat sample.

Seasonal distribution of pH in East Lake Sammamish (ELS) 34, Queens bog

As part of the PSWSMRP, pH data were collected at approximately two-week intervals at three stations on the *Sphagnum* mat. On fewer occasions, pH was measured from shore to shore along a north-south transect across the peatland, just east of the pipeline cut (transect B). All samples were taken from piezometers (Personal communication, R. Horner, May 2000). The center station (B3) was on the *Sphagnum* mat, and stations B1 and B5 are assumed to be in the north and south moats, respectively. It is not known, however, whether stations B2 and B4 were within the *Sphagnum* mat, in moat areas, or in areas where the mat was disintegrated. Table 3.6 shows average pH values for the transect.

TABLE 3.6 East Lake Sammamish 34 pH data.

pH data for Transect B, Sept 1990 - Dec. 1991 (transect extends north to south from lagg to lagg east of pipeline cut)					
	B1 (N moat)	B2	B3 (mat)	B4	B5 (S moat)
pH (avg.)	6.24	5.39	4.49	5.70	5.76
N (sample size)	8	10	11	7	8
S (standard deviation)	0.13	0.30	0.42	0.55	0.75

Data were collected from November 1990 to December 1991 and represent seasonal variability. In addition, the winter of 1990 was particularly wet, with major flooding occurring in the region. Station B1 in the north moat has a higher average pH than Station B5 in the south moat, 6.24 versus 5.76. The north moat is broader and receives small amounts of runoff from a county road. The pH is 4.49 at the center station (B3) and intermediate between the center and moat stations.

Monthly pH values for three transects within the center of the Sphagnum mat are shown in Figure 3.8.

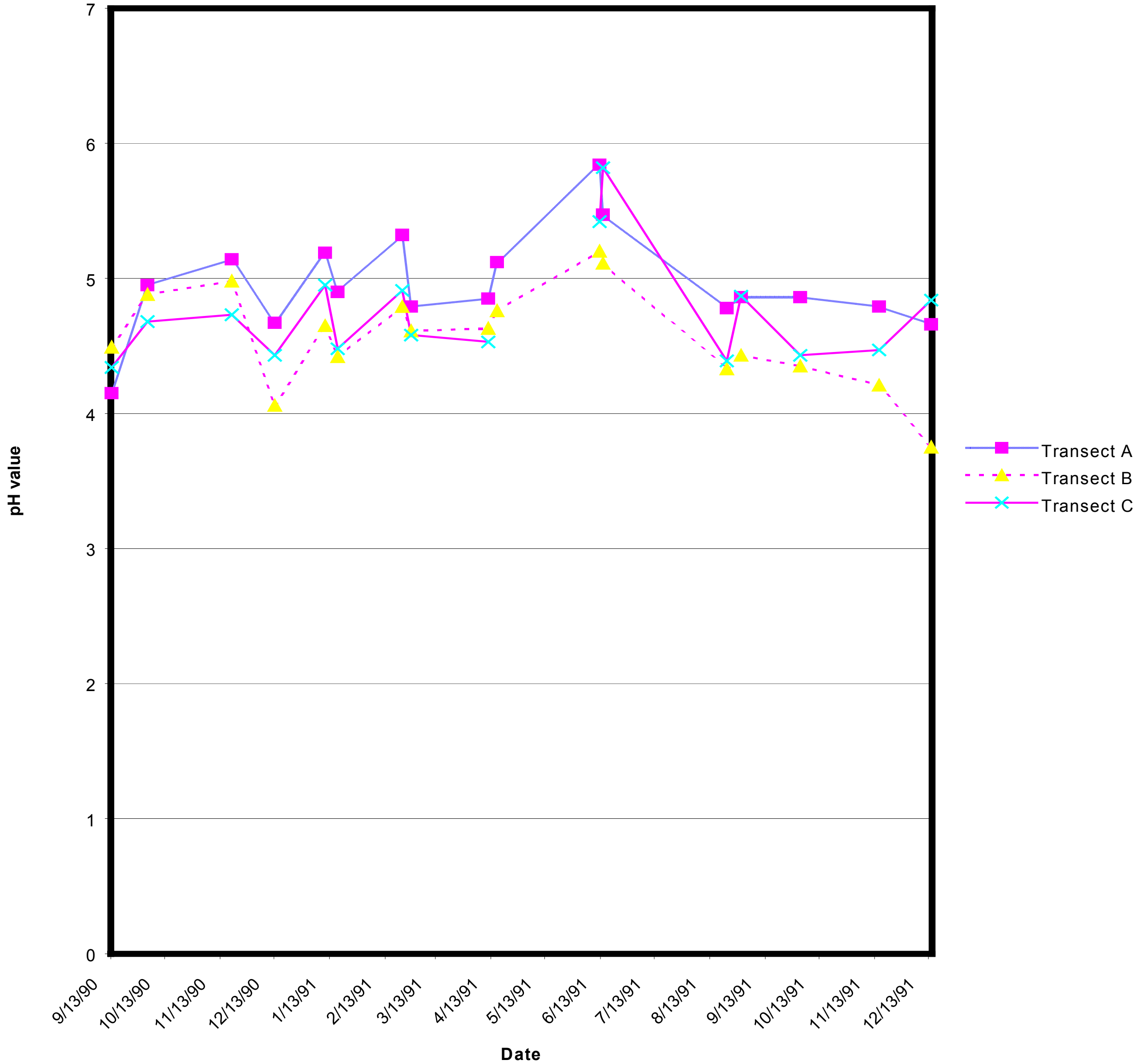


FIGURE 3.8 Seasonal changes in pH, ELS 34, Sept. 1990 - Dec. 1991

Transect A is through the western portion of the mat and transects B and C are through the eastern portion, with transect B being closer to the pipeline cut. It is not known to what extent, if at all, non-acid adapted plants had invaded the sampling stations at Transect B. The data show a general elevation of the pH (decrease in acidity) during the spring and summer (April through September). For transect B, the pH averages 4.5 for the winter (December –February) and 4.7 in the summer (July - September). However, for transect B, both the highest and lowest pH values (3.75 and 4.98) were in winter, obscuring clear seasonal trends. Variability at all stations is high.

This suggested trend toward more acidic conditions in the wet fall and winter months is not consistent with data collected on English bogs by Gorham (1956), who found that acidity increased in dry weather rather than wet weather. From the observation that rainwater is less acid than *Sphagnum* mat pool water, a decrease in acidity during wet periods seems logical. Also, observation of pH in *Sphagnum* hummocks shows increasing acidity in drier situations (see Chapter 4), a trend consistent with increasing summer acidity. Vitt et al., 1995, however, found very little seasonal change in surface water acidity in bogs and poor fens in continental Canada.

Vertical dissolved oxygen distribution in *Sphagnum* mats

Field measurements of the concentration of D.O. with depth are presented below. The technique used was to slowly insert a wooden dowel to a depth of about 2 feet and rotate it to enlarge the hole. The water was allowed to equilibrate for about an hour. The probe of a field YSI dissolved oxygen meter was then inserted in the hole to a measured depth. The probe membrane was changed and the meter calibrated prior to use. The meter reading was recorded when the readout remained constant for 3 minutes.

Three peatlands were investigated: Little Lake, Hoeven peat area and LCR 16. Little Lake is a fairly undisturbed *Sphagnum*-dominated peatland in Snohomish county. The watershed is forested, although forest harvesting occurred in the past. Three profiles were done on October 13, 1997 in different vegetation types. One profile was replicated. Surface D.O. (at about 4 inches below the water surface) ranged from 0.3 mg/L to 0.76 mg/L. At about 20 inches (51cm) D.O. read less than 0.07 mg/L. The lowest reading was 0.03 mg/L, taken in an area of open *Sphagnum* near the central open water pond.

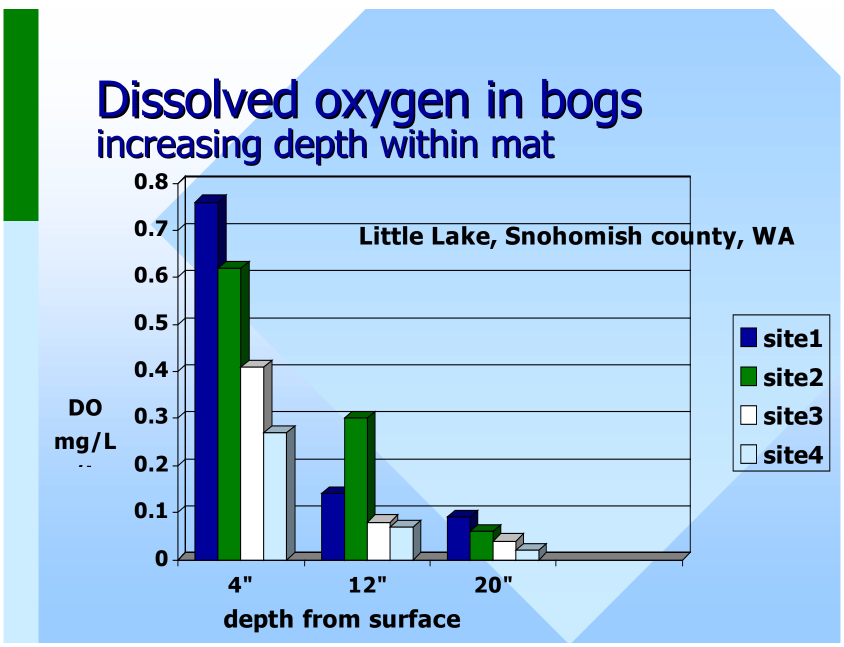


FIGURE 3.9 Vertical dissolved oxygen concentrations, Little Lake Bog, Snohomish, Washington.

Similar profiles were taken at Hoeven peatland on the same day. Hoeven peatland is about 2 km (1 mile) west of Little Lake, also in Snohomish county. More watershed clearing has occurred than at Little Lake, and a road traverses the edge of the peatland. Surface D.O. averaged 0.7 mg/L. Due to obstructions, the probe was only able to be inserted to a depth of 18 inches (46 cm), with a corresponding D.O. of 0.14 mg/L.

A similar set of samples was taken at LCR 16 in June of 1997. Two locations were sampled to a depth of about 30 inches (76 cm). Surface D.O. was about 1.4 mg/L. At 30 inches the D.O. reading averaged 0.7

mg/L. The greater depth of the acrotelm in LCR 16 could be related to the relatively greater water level fluctuations observed in the wetland, varying more than 40 cm (1.2 ft) in response to storm events (Shapiro, 1998). The PSWSMRP identified a threshold of 20 cm (0.7 ft) as characterizing wetlands with undisturbed watersheds, with significantly lower fluctuations hypothesized for peatland systems (Horner et al., 1996). Another method to establish the depth of the acrotelm is to insert a section of rebar into the mat. Rust will develop on the portion with available oxygen (personal communication, Dale Vitt, August 2000).

Fungal and bacterial assay

Acidic waters have a depauperate bacterial community, as bacteria are unable to thrive in acidic, anoxic conditions. In addition, van Breeman (1995) suggested that lack of available carbon, due to the refractory nature of carbon in *Sphagnum,* may also be a factor discouraging bacterial populations in acid peatlands. Fungal organisms, however, are reported to be less sensitive to pH extremes, and do relatively well in acid waters (Clark 1998; Moore and Bellamy 1974). In an attempt to use this information to better monitor changes induced by urbanization of the watershed, the King County Environmental Laboratory was asked to examine the microbiology of a conventional wetland and two peatlands, one a disturbed *Sphagnum*-dominated peatland, and the other an undisturbed *Sphagnum*-dominated peatland. A generic, low-cost microbial assay differentiating these wetlands was sought.

Differences were seen in the following plate counts: heterotrophic bacteria, filamentous mold, and yeast mold. Adenosine triphosphate (ATP) measurements and morphological type diversity richness indices were also determined. Water from the undisturbed peatland showed bacterial counts an order of magnitude lower than the non-peat-forming wetland sampled. However, the undisturbed peatland also had the lowest fungal counts, lower than either the undisturbed peatland or the conventional wetland. Bacterial diversity richness index was highest in samples incubated at neutral pH except for the undisturbed peatland sample, which showed a higher bacterial diversity richness index when incubated at pH 4.0. ATP concentrations were seen to correlate well with bacterial counts. The complete report is reproduced in Appendix C.

Enough differences were seen to use the plate counts to establish baseline conditions for a development proposal in the LCR 16 watershed. Mat pool water and moat water were examined on two occasions, once in February and once in June. Plate counts for heterotrophic bacteria and three fungal assays – filamentous mold, yeast, and yeast and filamentous mold combined – were carried out. The ATP concentrations and diversity richness indices were not determined in LCR 16. Results are in Table 3.7.

Distinct differences were seen between *Sphagnum* mat pools and the moat. Although numbers were higher in June than in February, mat samples had significantly lower bacteria on both occasions. Mold and yeast counts showed the same trend. Counts were much lower in the mat samples than in the moat samples in both June and February. These data call into question the belief that fungal communities (both filamentous and yeast molds) are tolerant of acidic conditions.

TABLE 3.7 Microbiological characteristics of Lower Cedar River 16

		Bacterial assay	Fungal assays		
		Heterotrophic plate count		Filamentous mold plate count	Yeast plate count
		CFU/1ml		CFU/1ml	CFU/1ml
Mat stations					
Date	Stn				
6/5/98	1	1,070		23	50
	2	540		15	17
2/26/99	1	85		20	400
	2	119		18	310
Moat stations					
6/5/98	3	78,000		230	3,100
	4	24,000		400	2,500
2/26/99	3	10,900		3,500	6,800
	4	13,700		2,800	5,800

Discussion and comparisons

Of the four *Sphagnum*-dominated peatlands examined here, the lowest pH and cation concentrations were seen in ELS 21 and LCR 16. ELS 21 also showed low alkalinity and cation concentrations in moat water, even though the pH of the moat was higher. This was surprising since the peatland moat received flow from two intermittent streams. The streams had relatively small basin areas, being at the basin headwater. PC 17 had higher pH and cation concentrations, both in the mat and the moat, but values are questionable because of evaporative effects. The pH of mat pool water for PC 17 was 4.7, about the same as ELS 34 (pH = 4.76 annual average).

Conductivity is lower in waters with low ionic concentrations and generally increases with pH (Malmer 1986). Thus the lower pH of water of *Sphagnum* mat pools would be expected to also show lower conductivity readings than moat water. ELS 21, LCR 16 and PC 17 all follow this pattern for corrected conductivity. No moat conductivity was taken for ELS 34, so comparison is not possible. In the one peatland with anion data, LCR 16, both Cl^- and $SO_4^=$ showed lower concentrations in the mat than in the moat. D.O. concentrations were lower in *Sphagnum* mat pool waters than in moat water for the two peatlands with enough data to allow comparisons.

Total phosphorus was determined for mat water in all four peatlands. In two of the systems, ELS 21 and LCR 16, pool water showed higher total phosphorus concentrations than in the moat water. PC 17 showed lower total phosphorus concentrations in the mat than the moat, but both values were very high. No moat nutrient data were taken in ELS 34, so comparisons are not possible. Total phosphorus values for mesotrophic lake waters in the Puget Sound area is about 0.010 to 0.020 mg/L (Metro 1994). In comparison, the values for both the *Sphagnum* mat and moat of these peatlands is quite high. Although soluble reactive phosphorus is typically lower than total phosphorus, it was also quite high for ELS 34 and PC 17 (SRP was not analyzed in LCR 16). Higher concentrations do not necessarily mean that phosphorus is more available to plants, however. Larsen (1982) for instance has shown that soil nutrients are unavailable at low pH. Similar mechanisms could be operating in peat systems.

Nitrogen concentrations were also fairly high, and were distributed between oxygenated forms (NO_2 and NO_3) and reduced forms (NH_3). Nitrate (or NO_2 + NO_3) was the prominent form of nitrogen in ELS 21, both in the mat and the moat. In LCR 16, NO_2+NO_3 and NH_3 were approximately evenly distributed. And in LCR 16 and PC 17, ammonia was the most prevalent form of nitrogen. Considering the four systems together, nitrate or NO_2 + NO_3 ranged from approximately 0.03 mg/L to 0.4 mg/L, an order of magnitude difference. Ammonia ranged from <0.029 mg/L to over 3 mg/L, about two orders of magnitude difference. The prevalence of the reduced form of nitrogen (ammonia) is likely related to low dissolved oxygen values in these systems. Curiously, the wetland with the highest ammonia concentration, PC 17, also had the highest D.O. concentration.

The high mat nutrient value could possibly be due to entrainment of peat or other detritus into the samples if they were unfiltered, or filtered with a relatively coarse filter size. Another possible reason for high values could be the method of sample collection in piezometer samples. Vitt et al. (1995) found increasing nutrient concentrations with depth in a study of several Alberta peatlands. For samples taken in piezometers, such as ELS 34 and LCR 16, high nutrient values may be related to the deeper sampling depth.

Comparing the four peatlands to Seattle area rainfall data, it is seen that the pH of two of the peatlands is comparable to rainwater pH of 4.7. Two of the peatlands have pH values lower than the rainfall average of 4.7-- ELS 21 and LCR 16. Cation concentrations in rainwater are about an order of magnitude lower than in *Sphagnum* mat pool water. Although nutrient data for rainwater are limited, concentrations of TP and SRP in rainwater, even for the enriched urban environments sampled, was an order of magnitude lower than for mat pool water. Bridgham et al. (1996) has recently called attention to data indicating that bogs are not necessarily deficient in measured nutrients as was often assumed. However, since export of nutrients may be related to accelerated rates of decomposition brought about by complex watershed or regional changes, e.g. forest clearing or climate change, Bridgham's finding may not be an intrinsic character of peatlands, but an indicator of destabilized conditions. These data support the findings of relatively high nutrient concentrations in *Spahgnum*-dominated peatlands, but again, it is unknown whether this situation is intrinsic to peatlands or a signal that increased rates of decomposition from disturbances in the watershed are creating this condition.

High nutrient and cation concentrations are of concern in evaluating peatland health. Fertilization experiments have not determined under what relative combination of enrichment regimes, that is, what combination of nitrogen, phosphorous and cation enrichment, *Sphagnum* is affected. However, it is clear that some combinations of enriched nutrients causes *Sphagnum* to die, both in the laboratory and in field experiments (Bridgham et al. 1996). For example, a field fertilization study in a Maine ombrogenous peatland caused death of the *Sphagnum* and replacement by other species (Bridgham et al. 1996).

Bacteriological sampling revealed that acidic waters of *Sphagnum* mat pools support fewer colony-forming-units of heterotrophic bacteria and fungus, both filamentous and yeast molds, than did moat water. Bacteriological assays hold promise as an early-indicator of changes in the chemical environment of acid waters. However, quantification of representative bacteriological counts for different seasons would be necessary before such data could be used reliably. The usefulness of plate counts to signal disturbance of an acidic peatland is reinforced by the pronounced increase in plate counts for a disturbed peatland investigated in the initial assay by the King County Environmental Laboratory (see report in Appendix C).

Relationship to other studies

No other water chemistry data from the western Washington area were located for this report. Limited data for Canadian peatlands have been published, with Burns bog, near Vancouver B.C. being the closest. Burns bog is a domed peatland[2] developed in the floodplain of the Fraser River. In the Burns Bog Synthesis Report (Hebda et al., 2000), bog water was characterized by a calcium content of 0 to 3 mg/L and a pH of 3.5 to 5.5. Bog water was from areas dominated by a *Sphagnum* mat. Non-mat water, from areas not *Sphagnum*-influenced, had a calcium concentration of greater than 10 mg/L and a pH between 5.0 and 8.0. Transitional water was defined as surrounding the *Sphagnum*-dominated water regions, and had values between the two, with calcium between 3 and 10 mg/L and pH between 4.5 and 6.0 (Balfour and Banack, 2000, summarized in Hebda et al., 20000).

It is not known how similar Burns bog may be to Puget Sound peatlands. However, if these categories were applied to Puget Sound *Sphagnum*-dominated peatlands, the following classifications would result:

- **Water from *Sphagnum* mats:** ELS 21 and LCR 16 would both correspond to bog water as defined in the Burns bog report based both on pH and calcium. ELS 34 has only pH data, which also indicate that it is within the suggested range for bog water.
- **Water from moats:** ELS 21 moat water falls into the transitional water category because of its higher pH, but the calcium concentration would be indicative of the bog water category. LCR 16 moat water had calcium concentration within the transitional range and pH was in the non-bog water range.

PC 17 was ignored for this exercise because the cation samples are probably not representative. In summary, the *Sphagnum* mat areas of the three peatlands with representative data would fit into the bog water category established in the Burns bog report. The moat waters would vary between transitional water and non-bog water.

[2] A domed peatland is one in which the peat is raised above the elevation of the surrounding land.

In addition to Burns bog, a number of peatlands in the Prince Rupert and Queen Charlotte Islands of British Columbia have been investigated (Vitt et al. 1989). Coastal British Columbia bogs and poor fens were reported to have a pH of between 4.1 and 4.8 and had low corrected conductivities, from 17 to 82 uS/cm (Vitt et al. 1989). Gignac and Vitt (1990) also investigated these peatlands, but reported the chemistry data by Twinspan-determined stand-group rather than by site. However, if the first three stand-groups are assumed to distinguish coastal bogs and poor fens, the data can be used for comparison. These stand-groups had corrected conductivities ranging from 11 to 24 uS/cm, and cations in the following ranges: calcium, 0.6 to 2.1 mg/L, magnesium, 0.3 to 1.2 mg/L, sodium, 2.2 to 7.9 mg/L and potassium, 0.9 to 4.8 mg/L. Values for pH were not given. Zoltai et al. (1988) also reported chemistry data from slope bogs in British Columbia (specific localities not given). Samples were collected from piezometers. Data from three sites assumed to be *Sphagnum*-dominated were reported. They had an average pH of 4.5. Cation concentrations were 0.24, 0.14 and 0.5 mg/L for calcium, magnesium and potassium, respectively. Chloride was 1.9 mg/L. Nutrients were 0.08 mg/L for ortho-phosphorus, 0.67 mg/L for nitrate, and 0.43 mg/L for ammonia. The high nitrogen values may be due to withdrawal of deeper water from the piezometers, as suggested for the ELS 34 and LCR 16 data. Other than the high nitrate and ammonia values in the Zoltai paper, these data bracket the same general range as the western Washington data, and are summarized in Table 3.8.

TABLE 3.8 Comparison of water chemistry of western Washington and Canadian peatlands.

		Sphagnum mat		"Bog water"	Sphagnum-dominated. B.C.		
		ELS21	LCR16	Burns bog	Vitt et al. 1990	Gignac et al.1990	Zoltai, 1988
					Prince Ruppert B.C.	Stand group1,2&3	B.C.
pH		4.2	4.2	3.5-5.5	4.1-4.8		4.5
cor.conductiv	uS/cm	22	9		17-82	11 --24	
Ca	mg/L	0.72	0.38	< 3.0	0.37-.42	0.6-2.1	0.24
Mg	mg/L	0.28	0.16		.35-1.6	0.3-1.2	0.14
Na	mg/L	0.59	0.78		1.9-14.0	2.2-7.9	
K	mg/L	0.5	1.28		0.07-.14	0.9-4.8	0.5
Cl	mg/L		1.77		23.4		1.9
SO4	mg/L		<1.18		1.9		
SRP	mg/L	< 0.005					0.08
TP	mg/L	0.072	0.23				
NO3	mg/L	< 0.34					0.67
NO2+NO3	mg/L		0.05				
NH3	mg/L	< 0.05	0.077				0.43

3.4 Groundwater Chemical Characteristics

Since the influence of groundwater in some classification schemes is one of the factors for distinguishing peatland type (bogs from poor fens), and since it constitutes an important gradient in peatlands, local groundwater chemistry is of interest. Two local groundwater data sets are presented in Table 3.9. One is for a typical glaciated plateau in the Issaquah area, remote from any *Sphagnum*-dominated

TABLE 3.9 Groundwater chemistry, King County locations

Issaquah Highlands area groundwater chemistry- SUMMARY
Nov. 1992 & April 1993

Parameter			n	Variance(s^2)	s
pH		6.72	16	0.8	1
alkalinity	mg CaCO3/	70.5	16	3015.5	55
acidity					
hardness	mg/L	69.1	16	1034.3	32
conductivity	umho/cm	115.3	15	4745.9	69
Ca	mg/L				
Mg	mg/L	36.3	16	1266.6	36
Na, dissolve	mg/L	11.7	16	146.0	12
K, dissolvec	mg/L	2.2	16	1.9	1
turbidity	NTU	1408.3	16	1498668.9	1224
sulfate	mg/L	5.3	16	8.3	3
Cl	mg/L	2.6	16	1.3	1
TP	mg/L	3.26	16	10.1	3
SRP	mg/L	0.02	16	0.0	0
NO3	mg/L	1.72	16	2.4	2
NH3	mg/L	0.10	16	0.0	0
TKN	mg/L	1.36	16	0.7	1

Petrovitsky Park, Lower Cedar River wetland 16

		Site 1(near moat)	Site 2 (upslope, 125 m)	
		n=1	n=1	
Feb-98				
pH		5.61	6.67	Measured in lab
alkalinity	mg CaCO3/	5.8	55.3	
acidity	mg CaCO3/	---	---	
hardness	mg/L	14.3	78.4	
conduc	umho/cm	---	---	
Ca	mg/L	3.15	6.15	
Mg	mg/L	1.56	15.3	
Na	mg/L	2.18	3.91	
K	mg/L	0.964	0.9	
turbidity	NTU	---	---	
sulfate	mg/L	26.3	5.81	
Cl	mg/L	1.9	3.6	
TP	mg/L	0.103	0.035	
SRP	mg/L	0.011	0.005	Filtered
NO3+NO2	mg/L	1.9	0.468	
NH3	mg/L	---	---	
TKN	mg/L	---	---	

Note: The high turbidity value for Issaquah Highlands may indicate soil or salts on the sample.

peatland locations (Herrera Environmental Consultants 1993). The other is adjacent to LCR 16 on the Maple Valley plateau. The LCR 16 data are of particular interest since the two wells prescribe a gradient, one well being adjacent to the *Sphagnum* mat and the other upland approximately 122 m (400 feet) (Shapiro & Associates 1998).

The Issaquah Highlands data set is considered representative of groundwater in glacial till areas of King County. Samples were taken from shallow wells installed at a depth of 12-15m (4-5 feet). Samples were not collected if less than 15 cm (6 inches) of water was in the well so as to avoid excessive turbidity in the samples. Groundwater pH is consistently about 6.7, significantly higher than *Sphagnum* mat and moat stations. Cation concentrations vary.

Groundwater data for LCR 16 shows that nearer the wetland moat, cation concentrations are reduced from those upslope a short distance, particularly for magnesium which is 1.6 mg/L near the moat, but 15 mg/L upslope. Contrary to this trend, sulfate decreases with distance from the peatland. These data show that groundwater adjacent to the moat may in fact be influenced by the peatland rather than by groundwater. That is, the peatland may be recharging the aquifer rather than being a groundwater discharge point, at least under winter rainfall conditions. In general, the groundwater data show higher cation concentrations (except for potassium) and higher phosphorous and nitrogen concentrations than found in *Sphagnum* mat pool water.

3.5 Chemistry of Marshes, Swamps and Other Waters in the King County Area

Comparison with wetlands that are not peat-accumulating

It is instructive to look at the chemistry of other wetlands in the western Washington area to determine the differences between acidic peatlands and other wetlands. The PSWSMRP compiled data for marsh and swamp wetlands in the King County area (Horner, et al. 2000). Over 50 wetlands were studied for a five-year period. Wetlands in the study were classified as having non-urban, moderately urban or highly urban watersheds. Non-urban wetlands are those with watersheds with at least 40% forest cover and less than 4 per cent impervious surface in the watershed. Highly urban wetlands are

those 7% or less forest cover and 20% or more impervious surface. Moderately urban wetlands had intermediate levels of forest cover and impervious surface in the watersheds.

Water samples were taken in open water near the surface. Temperature, D.O., conductivity and pH were measured in the field. For non-urban wetlands, pH averaged about 6.4 (standard deviation, s = 0.5), increasing to 6.7, as urbanization in the watershed intensified (s = 0.6). Dissolved oxygen averaged 5.7 mg/L, decreasing to less than 5.4 as urbanization increased. Cations, anions and alkalinity were not measured. Conductivity averaged 73 μS/cm in non-urban wetlands and doubled to about 150 μS/cm in highly urbanized watersheds.

Total phosphorus concentrations averaged 0.05 mg/L in non-urban wetlands, doubling in wetlands with highly urbanized watersheds. Nitrate plus nitrite concentrations were fairly constant, averaging about 0.4 mg/L in both non-urban and highly urban watersheds. However in moderately urban wetlands, concentrations increased to about 0.60 mg/L on average. Table 3.10 summarizes the chemical character of typical non-acid wetlands.

TABLE 3.10 Water chemistry characteristics of western Washington wetlands

Urban Status	Statistic	pH	DO (mg/L)	Cond. (μ S/cm)	TSS (mg/l)	NH_3-N (μ g/l)	NO_3+NO_2-N (μ g/l)	SRP (μ g/l)	TP (μ g/l)	FC (CFU/100 ml)	Cu (μ g/l)	Pb (μ g/l)	Zn (μ g/l)
N	Mean	6.38	5.7	72.5	<4.6	<59.9	<368.2	<17.6	52.3	>271.3	<3.3	<2.7	<8.4
	Maximum	7.65	11.3	230.0	73.0	1373.0	3200.0	414.0	850.0	6240.0	15.0	21.0	49.0
	Std. Dev.	0.53	2.6	63.8	>8.5	>129.3	>484.6	>47.6	86.6	>1000.4	>2.7	>2.8	>8.3
	CV	8%	45%	88%	>185%	>216%	>132%	>271%	166%	>369%	>80%	>105%	>99%
	Median	6.36	5.9	46.0	2.0	21.0	111.5	6.0	29.0	9.0	<5.0	1.0	5.0
	n	162	205	190	204	205	206	200	206	206	93	136	136.0
M	Mean	6.54	<5.5	142.4	<9.2	<125.7	<598.2	<31.5	92.5	>2664.8	<3.7	<3.4	<9.8
	Maximum	7.88	14.8	275.0	180.0	2270.0	7210.0	280.0	780.0	359550.0	7.0	13.0	33.0
	Std. Dev.	0.82	>3.6	72.8	>21.6	>266.8	>847.2	>37.9	91.8	>27341.7	>1.9	>2.7	>7.2
	CV	13%	>66%	51%	>235%	>212%	>142%	>120%	99%	>1026%	>51%	>79%	>73%
	Median	6.72	5.1	160.0	2.8	43.0	304.0	16.0	70.0	46.0	<5.0	3.0	8.0
	n	132	173	161	175	177	177	172	177	173	78	122	122.0
H	Mean	6.73	<5.4	150.9	<9.2	<68.3	<395.4	31.2	109.5	>968.6	<4.1	<4.5	<20.2
	Maximum	7.51	10.5	271.0	87.0	516.8	1100.0	79.0	1940.0	38000.0	12.0	22.0	73.0
	Std. Dev.	0.57	>2.9	85.5	>15.1	>104.4	>239.4	15.7	233.5	>4752.8	>2.5	>4.0	>16.7
	CV	9%	>53%	57%	>164%	>153%	>61%	50%	213%	>491%	>62%	>89%	>83%
	Median	6.88	6.3	132.2	4.0	32.0	376.0	28.2	69.0	61.0	<5.0	5.0	20.0
	n	52	67	61	66	67	67	65	67	66	29	44	44.0

Note: Nonurban watersheds (N) = less than 4% impervious land cover and greater than or equal to 40% forest. Highly urbanized watersheds (H) = greater than or equal to 20% impervious and less than or equal to 7% forest. Moderately urbanized watersheds (M) = wetlands not fitting either of the other categories.

Sphagnum-dominated peatlands stand out as having much lower pH, lower conductivity and higher total phosphorus concentrations than conventional wetlands. The corrected conductivity of *Sphagnum* mat pool water was often less than 35 μS/cm, a pronounced difference from the non-peat accumulating wetland average of 70 - 150 μS/cm, reflecting differences in ion concentration. Perhaps unexpectedly, TP concentrations were higher in *Sphagnum*-dominated peatlands than the average for non-peat accumulating wetlands, even for wetlands with highly urbanized watersheds.

However, since TP analysis involves the digestion of the sample with a strong acid, any organic material in the peatland samples would be digested and reported as TP. It is not unreasonable that mat pool water might contain small *Sphagnum* fragments or other organic compounds that would not be filtered out of samples.

Soluble phosphorus, or SRP values, would be more indicative of available phosphorus, and allow a better comparison of nutrient status of acid peatlands and conventional wetlands. However, SRP values were not reported by the PSWSMRP. The SRP concentrations for the acid peatlands presented in this chapter are also, however, quite high in comparison with area lakes, as will be established below.

In addition to chemical parameters, the PSWSMRP (1996) offered guidelines about water level fluctuation ranges observed in wetlands with high species richness of plants and amphibians. It was found that the mean annual water level change between the annual average base water level and highest monthly crest gage readings remained less than 20 cm (8 inches) in wetlands with the highest species richness. Further, the report found water level fluctuations occurred for shorter durations in wetlands with high species richness. Although *Sphagnum*-dominated peatlands were not studied in the program, a recommendation was made that priority peatlands should be managed to maintain the pre-developed magnitude and duration of water level fluctuation throughout the entire year.

Comparison with Small Streams

Unlike wetlands, which are sinks for nutrients and many other parameters, flowing water is thought to exhibit lower nutrients and higher D.O. concentrations than wetlands. Two small streams in the Grand Ridge area of Issaquah are typical of others in King County. Eleven samples taken at approximately monthly intervals, form a basis for comparison (Herrera Environmental Consultants, 1993b). Data are shown in Table 3.11. Values of pH were circumneutral and D.O. values were often at saturation (10 - 12 mg/L). D.O. dropped to 5 - 6 mg/L in summer as flows decreased and temperatures increased. TP was often below the detection limit of 0.01 mg/L, but occasionally reached 0.2 mg/L. Nitrate, however, was relatively high, ranging from about 0.3 mg/L to 4.5 mg/L.

In data collected by Metro (1994) from 50 western King County streams, pH, hardness, conductivity and nutrient concentrations were tracked monthly from 1991 to 1993. Of the 50 streams monitored, half had a pH of 7.5 or above and a conductivity of 130 μS/cm or above, and D.O. of 10 mg/L or above. Hardness ranged from 20 to 90 mg/L, and streams in areas with coal deposits had higher concentrations. Nutrient concentrations for half the streams averaged 0.048 mg/L TP or greater, 0.63mg/L NO_2+NO_3 or greater, and 0.015 mg/L or greater ammonia concentrations. From this data, local streams would seem to be characterized by low phosphorus but relatively high nitrogen concentrations.

Lakes

Small lakes in the King County area often show much lower nutrient concentrations than streams. Data for 1991 to 1993, showed that most small lakes averaged from 0.005 to 0.05 mg/L TP (Metro 1994). The pH ranged from a low of 6.7 to about 8.0. Conductivity ranged from 35 to 170 μS/cm, with tea-stained lakes showing lowest conductivity. Alkalinity was not measured.

Lake Washington is a large lake with significant watershed development since the 1950s.

TABLE 3.11 Chemistry of small streams in the King County area

Grand Ridge first-order streams

		Pole creek	N	Mine Creek	N
pH		7.01	9	7.17	8
D.O.	mg/L	10.4	7	9.18	6
alkalinity	mg CaCO3/L				
hardness	mg/L	28.2	7	24.24	7
conduc	uS/cm	79	9	78.5	8
Ca	mg/L				
Mg	mg/L				
Na, dissolved	mg/L				
K, dissolved	mg/L				
turbidity	NTU	0.67	9		
sulfate	mg/L				
Cl	mg/L				
TP	mg/L	< 0.029	9	<0.074	8
SRP	mg/L	< 0.006	9	<0.007	8
NO3	mg/L	1.55	9	2.21	8
NH3	mg/L			<0.012	2
TKN	mg/L				

N = number of samples

The University of Washington has monitored the lake since the 1960's, and has documented some interesting trends. In particular, alkalinity concentrations have shown a long-term increase over time. Values in 1991 to 1992 ranged from about 36.5 to 38.5 mg $CaCO_3$/L. The pH was slightly basic, ranging from 7.5 to 8.6 in the same time period. Limited data on cations showed Ca concentrations at about 8.8 mg/L, Mg at 3.4 mg/L, Na at 4.2 mg/L, and K at 1.1 mg/L (Personal communication, S. Abella, May, 1996). Nutrient data for the 1991-92 time period showed TP concentrations ranging from 0.007 to 0.026 mg/L. Nitrate was much more variable, ranging from below the detection level of 0.002 mg/L to 0.27 mg/L.

Urban Runoff

Alkalinity concentrations due to increased contact with the soil or other surfaces can reach extremes in urban stormwater runoff, particularly in runoff draining areas with cement infrastructure. Although alkalinity *per se* is seldom collected when monitoring urban runoff, hardness and conductivity, which are more frequently collected, can give an indication of cation enrichment. Typically, hardness concentration is lower than alkalinity for the same sample. This is because hardness is the sum of only two cations, calcium and magnesium, whereas in alkalinity determinations, all cations affect the established equilibrium determined by titration. Nutrients are also often high in urban runoff. Typical urban runoff concentrations for selected chemical parameters are given in Table 3.12. Hardness in the range of 30 - 40 mg/L was seen in two residential developments from the Seattle area, (King County 1997). In a large data set collected in the 1980s in Bellevue, Washington, conductivity in stormwater runoff had median

TABLE 3.12 Untreated Urban Runoff , Seattle, WA Area

	pH	(N)	Conductivity umho/cm	(N)	Hardness mg/L	(N)	TP mg/L	(N)	SRP mg/L	(N)	NH3 mg/L	(N)	NO2+NO3 mg/L	(N)
Meridian Green residential development, Storm runoff, 1993														
Average					32.1	(6)	0.065	(7)						
Std. Dev.					12.4		0.04							
Glacier Ridge residential development, Stormflows in small stream														
Average					40.8	(16)			0.051	(16)				
Std.Dev.					19				1.8					
Bellevue area runoff data (NURP studies, Prych, E. and J.C. Ebbert, 1986)														
148th Ave SE														
Average	6.7	(305)	47	(369)			0.15	(198)					1.2	(189)
Lake Hills														
Average	6.7	(430)	33.0	(515)			0.15	(266)					0.98	(268)
Surrey Downs														
Average	6.7	(358)	44.0	(415)			0.14	(222)					1.10	(239)
Bellevue area runoff data, Lakemont area (1999)														
Average							0.106		0.03		0.04		0.77	

values ranging from 33-47µS/cm. Stormwater nutrient data for urban runoff are also available in the Seattle area. One residential site averaged 0.065 mg/L TP, the other 0.05 mg/L SRP. The Bellevue sites had higher median TP values, at 0.15 mg/L.

In a more recent study in the Lakemont area of Bellevue, TP values were 0.106 mg/L and SRP was 0.03 mg/L. Nitrate values were high, 0.77 mg/L, with 0.04 mg/L ammonia (City of Bellevue, 1999).

Summary and conclusions

Key parameters for *Sphagnum* mat pool water, moat water, and other fresh waters are summarized in Table 3.13. In comparing pH, alkalinity, cations and anions, it is concluded that urban runoff shows the most extreme differences from waters of *Sphagnum*-dominated peatlands, and poses a concern for the maintaining the integrity of peatlands, particularly in areas undergoing rapid growth and development pressure. Calcium seems to be a key parameter in differentiating between acid peatlands and other wetlands (Malmer et al. 1992). This conclusion was also reached in the Burns Bog Synthesis report (Hebda et al., 20000). Calcium, however, is not typically monitored in urban runoff, since it is not toxic to most aquatic organisms and is a typical component of the carbonate-bicarbonate buffering system prevalent in most surface waters. So although calcium concentration is a good predictor of potential

TABLE 3.13 Comparison, *Sphagnum*-dominated peatlands and other surface water chemistry

		Sphagnum mat ELS21	LCR16	Non-*Sphagnum* wetlands (non-urban)	Rainwater (Patterson Cr)	Small streams (Grand Ridge)	Storm runoff (Lakemont)	Groundwater (Grand Ridge)
pH		4.2	4.17	6.4	4.7	7.1		6.7
alkalinity	mg/L CaC	<1	< 1				30 *	70
conducti	uS/cm	42	32.6	73	12	79		115
correcte	uS/cm	22	9.3					---
Ca	mg/L	0.72	0.38		0.023 [1]			
Mg	mg/L	0.28	0.16		0.019			36
Na	mg/L	0.59	0.78		0.164			12
K	mg/L	0.5	1.28		0.017			2.2
sulfate	mg/L		< 1.18		0.35			5.3
Cl	mg/L		1.77		0.32			2.6
DO	mg/L	1.9	1.4					
turbidity	NTU	17						
TP	mg/L	0.07	0.23	0.052	0.03	< 0.05	0.106	3.3
SRP	mg/L	< 0.005			0.016	<0.007	0.03	0.02
NO3	mg/L	< 0.34			0.28	1.9		1.7
NO2+NC	mg/L		0.05	< 0.37			0.77	
NH3	mg/L	< 0.05	0.077	0.06	0.145	<0.012	0.04	0.1
TKN	mg/L		3.55		0.648			1.36

[1] Shaded cells are from Olympia, WA, NOAA data for 1995-1998
[*] Data from Meridian Green residential development

impacts to acidic peatlands, other parameters that are more commonly collected in urban runoff studies are recommended as indicators of potential impact. Hardness, alkalinity, conductivity and pH are also good indicators of potential impact to *Sphagnum*- dominated peatlands, and more commonly monitored. Although not discussed in this chapter, nitrate has been found in fertilization experiments to be a limiting nutrient in *Sphagnum*-dominated peatlands. It is also possible that increasing nitrogen inputs could stimulate the growth of woody plants, shade the *Sphagnum* and result in long-term changes in the plant community (Aerts et al. 1992).

Two direct physical measurements are also excellent indicators of peatland health: 1) the depth of measurable D.O. concentrations, or depth of the acrotelm and 2) the magnitude and duration of water level fluctuations, as measured by the excursion from an average base water level. Some authors define the acrotelm in terms of either the height of the summer water table (Malmer 1986; Hebda et al., 20000) or water level fluctuation (van Breeman, 1995) rather than D.O. depletion, as did Ingram (1978). The Burns Bog Synthesis Report (Hebda et al., 20000), citing Dierssen and Dierssen (1984), Damman and French (1987) and Verry (1997) as sources, states that a summer water table below 30 to 40 cm (12 to 16 inches) for long intervals jeopardizes the peat-forming community, favoring the growth of woody plants, which in turn increases the rate of water table decline through evapotranspiration. Takagi et al. (1999) reported a 23% greater loss of moisture in summer from portions of a peatland covered by vascular plants than from areas covered only by *Sphagnum*, providing direct evidence for a mechanism that could result in the deepening of the acrotelm. The deepening of the acrotelm is important because of the increase in the rate of decomposition that accompanies it. As noted in the next section, this increased decomposition can increase the loading of nutrients to downstream lakes and embayments, causing accelerated eutrophication. It also causes changes in the density of the upper peat layers, which in itself can affect the composition of the plant community. Direct shading by woody species also causes changes in the plant community, since many *Sphagnum* species are intolerant to shading (Crum 1992) (also see Chapter 4 for additional discussion).

A minimal monitoring program to assess changes in the status of *Sphagnum*-dominated peatlands should include the following:

- use of rebar inserted into the *Sphagnum*, or other technique to indicate the depth of the acrotelm,
- hydrological measurements, particularly of the summer water level and water level fluctuation throughout the rainy season,
- annual determination of pH and corrected conductivity, and
- determination of changes in calcium and nitrogen loading.

3.6 Enrichment in flow downstream of peatlands

When decomposition rates in peatlands increase, they can yield significant nutrient loads to downstream lakes and embayments. Evidence of this can be seen in a study of Pine Lake, a small eutrophic lake on the east Lake Sammamish plateau near Issaquah, WA. A watershed loading study was done in 1979 and 1980 by the U.S. Geological Survey and the University of Washington (Dion et al. 1983; Welch et al. 1981). In the study, external sources of nutrients were identified and monitored to create an annual nutrient budget for the lake. Among the inputs were seven small streams, one draining a wetland complex containing a *Sphagnum*-dominated peatland. The *Sphagnum* area was referred to as "swamp" and the potential for peat decomposition to contribute excess nutrient loading was not directly recognized.

TP concentrations were measured from December 1979 to April 1980 for all seven inflow streams. Mean TP concentration ranged from about 35 to 73 mg/L for six of the tributaries. The seventh tributary with the *Sphagnum*-dominated peatland drainage, averaged 163 mg/L for the same period. This difference was determined to be statistically significant using non-parametric multiple comparison tests (Welch et al. 1981). The authors noted as interesting the constancy of the high nutrient concentrations from the seventh tributary, even in winter. The authors noted that on one occasion the pH of the stream was as low as 4.5. Table 3.14 summarize the data.

TABLE 3.14 Stream TP concentrations draining till watersheds and a *Sphagnum*-dominated peatland in the Pine Lake watershed (December 1979 - April 1980)

Streams no.	1	2	3	4	5	6	7 (drains *Sphagnum* peatland area)
Mean TP (mg/L)	37	73	34.5	44.5	31.5	39.1	163
S.E. (standard error)	4.5			6.2			7.3
N (sample size)	14			12			13
Average non-*Sphagnum* streams:	43.3 mg/L						163

The *Sphagnum*-dominated peatland contributing these high nutrients is part of wetland ELS30. It is a peatland complex that contains multiple community types with a *Sphagnum* community in the center. The *Sphagnum* portion of the peatland is identified as Mukilteo peat with Seattle Muck surrounding it (1973 King County Soil Survey). Figure 3.10, shows the ELS30 watershed on a 1995 aerial photo. A portion of

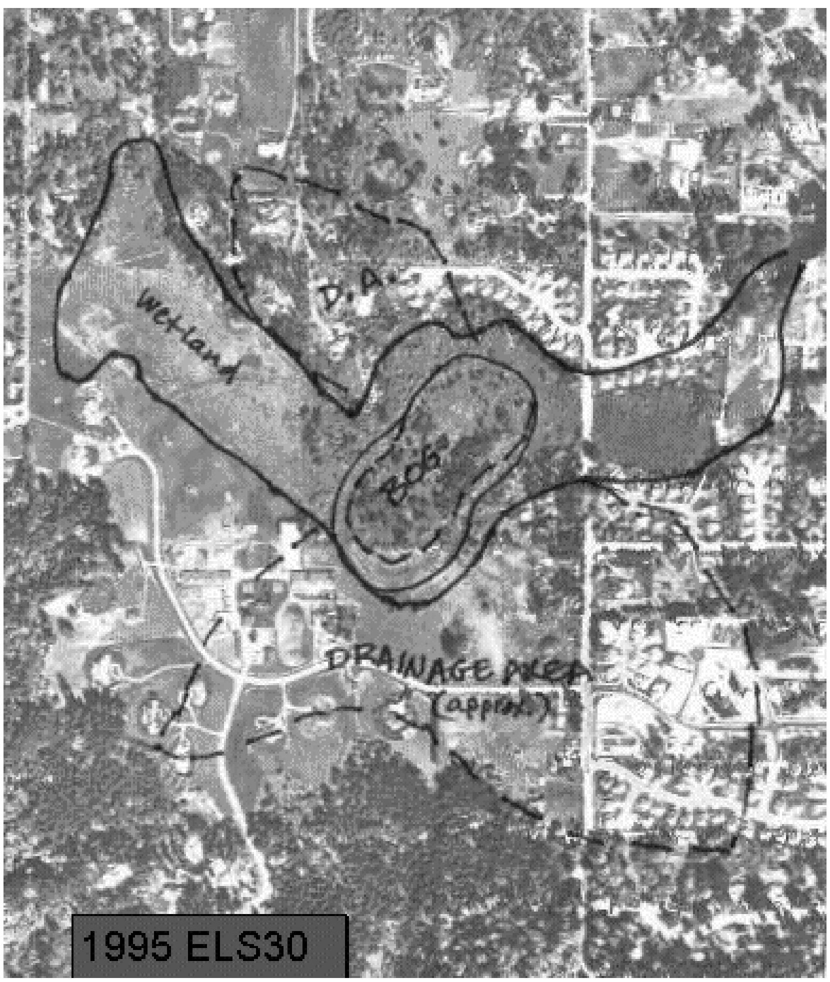


FIGURE 3.10 Land use in the ELS 30 Watershed, 1995

N

this wetland was farmed as a blueberry farm during this time period (personal communication, Eileen Stahl, April, 2000). In a 1997 field survey, a large horse stable was noted within the peatland watershed (King County, 1997). The 1936 air photo shows that over half of the bog drainage area to the peatland was already cleared (Figure 3.11). The Pine Lake Management Plan recommended that the wetland outflow be diverted to the Pine Lake outlet stream, by-passing the lake (Harper-Owes 1981). Stabilization of the peatland system was not identified as an option.

The Pine Lake study, finished in 1981, observed that at that development density in the watershed was low. However, increased runoff from the clearing of forest land, and lack of construction erosion control, or poor farm management practices may have contributed substantial suspended solids loads to the wetland for several decades (since 1936). The increased volume of runoff water caused by forest clearing could have increased water level fluctuations, subjecting more of the upper peat layer to oxygen, accelerating aerobic decomposition. These effects would deepen the acrotelm. Whatever the mechanism, it is clear that decomposition of peat was contributing substantial nutrients to Pine Lake. Other investigators have also documented downstream nutrient enrichment associated with peatlands. Malmer (1962) observed that it is possible for carbon loss from plant litter to be three times higher in fen peatlands than from a comparable ombrogenous bog site. It is not the status of the peatland as bog or fen that is crucial, however, but the rate of decomposition in the peatland. If anthropogenic or natural factors cause the rate of decomposition in a peatland to increase, increased nutrient export is likely.

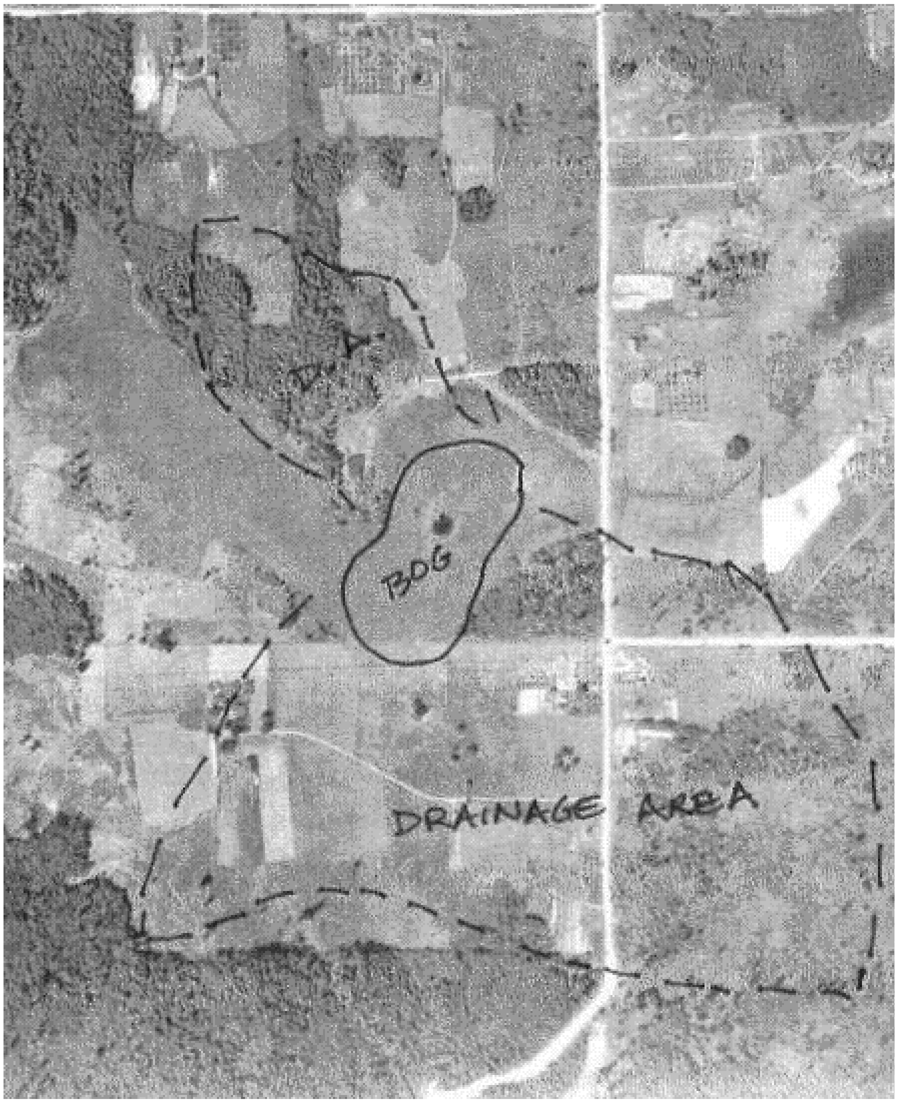
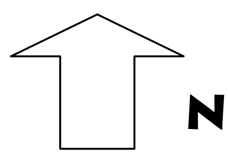


FIGURE 3.11 ELS30 watershed, 1936 air photo



3.7 Chapter Three References

Aerts, R., B. Wallen and N. Malmer, 1992. Growth-limiting nutrients in Sphagnum-dominated bogs subject to low and high atmospheric nitrogen supply. J. of Ecology 80: 131-140.

Bridgham, S.D., J. Pastor, J.A.Janssens, C.Chapin and T.Malterer, 1996. Multiple limiting gradients in peatlands: a call for a new paradigm. Wetlands 16(1): 45-65.

City of Bellevue, 1999. Lakemont Storm water treatment facility monitoring program: final report. City of Bellevue Utilities Department and Shapiro and Associates, Inc.

Clark, Joe, 1998. Wetland bog characterization. King County Environmental Laboratory, Microbiology section. Seattle, WA (presented in Appendix C of this report)

Clymo, R.S., 1963. Ion exchange in *Sphagnum* and its relation to bog ecology. Annals of Botany 27(106): 309-324.

Clymo, R.S., 1964. The origin of acidity in *Sphagnum* bogs. The Bryologist 67: 427-431.

Clymo, R.S., 1978. A model of peat bog growth. IN: Production ecology of British moors and montane grasslands. Edited by O.W. Heal and D.F.Perkins. Ecol. Stud. 27: 849-869.

Crum, Howard., 1992. A Focus on Peatlands and Peat Mosses. The University of Michigan Press, Ann Arbor, Michigan.

David Evans & Associates, Inc., 1993, Appendix L. Wetland Vegetation and Water Quality Conditions in ELS21. June 16, 1993. Draft Environmental Impact Statement for The Trossachs, By Meyer, Jeff, Lisa Vogel and Tom Duebendorfer, Bellevue, WA

David Evans & Associates, Inc., 1997, Monitoring Report for Wetlands ELS21, A, J and M Trossachs, Brighton's Landing and Belvedere Park Properties (1996 and 1997 conditions), Bellevue, WA

David Evans and Associates, Inc., 1998. Wetland Vegetation and water Quality Conditions of Wetland 3 [PC17] on Beaver Lake Estates Phase II : Final Report. ENWX0032, August 28, 1998, Bellevue, WA 98005

Dion, N.P, S. Sumioka, and T. Winter, 1983. General Hydrology and External Sources of Nutrients Affecting Pine Lake, King County, WA. U.S.Geological Survey, Water Resources Investigation Report 83-4057. Tacoma, WA

Gignac L.D. and D.H.Vitt, 1990. Habitat limitations of *Sphagnum* along climatic, chemical and physical gradients in mires of western Canada. The Bryologist 93(1): 7-22.

Gorham, Eville, 1956. On the chemical composition of some waters from the Moor House Nature Reserve. Journal of Ecology 44: 375-382.

Gorham, E., S. Bailey and D. Schindler. 1984. Ecological effects of Acid Deposition upon Peatlands: A Neglected Field in Acid Rain Research. Can. J. Fish. Aquat. Sci. 41: 1256-1268.

Gorham, Eville, 1967. Some chemical aspects of wetland ecology. Annual Muskeg research Conference Proceedings 12: 20-38.

Harper-Owes, Inc., 1981. Pine Lake Restoration Analysis; Final Report. 1981. Seattle WA, 98104

Hebda, R.J., K. Gustavson, K. Golinski, and A.M. Calder. 2000. Burns Bog Ecosystem Review Synthesis Report for Burns Bog, Fraser Delta, South-western British Columbia, Canada. Environmental Assessment Office, Victoria, B.C. Also online at:: http://www.eao.gov.bc.ca/special/burnsbog/reports/final/fr1.htm

Hemond, H.F, 1980. Biogeochemistry of Thoreau's bog, Concord Massachusetts. Ecological Monographs 50(4): 507-526.

Herrera Environmental Consultants, 1993a. Potential changes in wetland pH and alkalinity as a result of urban runoff. Unpublished report for the Blakely Ridge Development, submitted to King County Surface Water Management Division, Seattle, WA (now the Water and Land Division of the King County Department of Natural Resources).

Herrera Environmental Consultants, 1993b. Surface Water Quality Evaluation, Grand Ridge Proposed Development Site. Seattle, WA 98109.

Horner, R.R., S.S. Cooke, L.E.Reinelt, B.L.Taylor, K. A. Ludwa and N. Chin, 2000, Water quality and soils IN: Wetlands and Urbanization: Implications for the Future., Ed: Amanda Azous and R. Horner. Lewis Publishers, New York, Washington D.C., London.

Hutchinson, G.E, 1957. A Treatise on Limnology, Volume I: Geography, Physics and Chemistry. John Wiley & Sons, Inc., New York.

King County, 1997. Monitoring data in support of the King County Stormwater Management Program 1996-2000, Water & Land Resource Division, Seattle, WA

King County, 1997. King County Bog Inventory, Department of Natural Resources, Water & Land Resources Division and Cooke Scientific Services, Inc. Updated 1999.

Larsen, J.A., 1982 Ecology of the Northern Lowland Bogs and Conifer Forests. Academic Press.

Malmer, N., 1986. Vegetational gradients in relation to environmental conditions in northwestern European mires. Can J. Bot. 64: 375-383.

McQueen, Cyrus B., 1990. Field Guide to the Peat Mosses of Boreal North America. University of New England Press, Hanover and London.

Metro, 1994. Water Quality of Small Lakes and Streams, Western King County, 1990-1993. King County Department of Metropolitan Services, Seattle, WA 98104.

Mitsch W.J. and J.G.Gosselink, 1993. Wetlands, chapter 12 Northern peatlands and bogs. Van Nostrand Reinhold, New York.

Moore P.D. and D.J. Bellamy, 1974. Peatlands. Springer-Verlag.

Munson, R.K., S. Gherini, 1993. Influence of organic acids on the pH and acid-neutralizing capacity of Adirondack lakes. Water Resources Research 29(4): 891-899.

National Oceanic and Atmospheric Administration website, May, 2000. http://bgs.usgs.gov/acidrain/index.html. National Atmospheric Deposition Study and Precipitation Chemistry, Bellingham and Olympia, Washington stations.

Oliver, B.G., E. Thurman and R. Malcom, 1983. The contribution of humic substances to the acidity of colored natural waters. Geochimica et Cosmochimica Acta 47: 2031-2035.

Personal communication, Sally Abella, UW graduate student, email data, May, 1996.

Personal communication, Dr. Richard Horner, Research Associate Professor, University of Washington, Seattle, WA. Unpublished data.

Personal communication, Lorin Reinelt, Sr. Water Quality Engineer, King County Water & Land Resources Divisions, May, 2000.

Personal communication, Eileen Stahl, Pine Lake watershed resident, April, 2000.

Prych, E. and J.C.Ebbert, 1986. Quantity and Quality of Storm Runoff from three urban catchments in Bellevue, WA. Water Resources Investigations report 86--4000, U.S.Geological Survey, Tacoma, WA.

Shapiro & Associates, Inc, 1998. McGarvey Park Baseline Monitoring Results. Submitted to King County Dept. of Development and Environmental Services, Renton, WA.

Standard Methods for the Examination of Water and Wastewater, 1992. Ed: Greenberg, Arnold, L. Clescerl and A. Eaton. American Public Health Association, American Water Works Association, Water Environment Federation. Washington DC 20005

Thurman, E.M., 1985. Organic Geochemistry of Natural Waters. Martinus Nijhoff/Dr W. Junk Publishers, Dordrecht/Boston/Lancaster.

van Breeman, N., 1995. How *Sphagnum* bogs down other plants. TREE 10(7): 270-275.

Vitt, D. H., D. G. Horton, N. G. Slack and N. Malmer, 1989. *Sphagnum*-dominated peatlands of the hyperoceanic British Columbia coast: patterns in surface water chemistry and vegetation. Can. J. For. Res. 20: 696-711.

Vitt, D. and P. Kuhry, 1992 IN: Kuhry, P., B. Nicholson, D. Gignac, D. Vitt and S. Bayley, 1993. Development of Spahgnum-dominated peatlands in boreal continental Canada. Can. J. Botany 71: 10-22.

Vitt, D., S. Bayley, T. Jin, 1995. Seasonal variation in water chemistry over a bog-rich fen gradient in continental western Canada. Can. J. Fish. Aquat. Sci. 52: 587-606.

Welch, E.B., M. Perkins, G. Pelletier and R. Zisette. 1981. The Trophic State and Phosphorus Budget Study of Pine Lake, Washington. Department of Civil Engineering, University of Washington, Seattle, WA 98195.